Corso di Laurea in Fisica - UNITS

ISTITUZIONI DI FISICA PER IL SISTEMA TERRA

IFST

(138SM)

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System

- A **system** is a set of interacting or interdependent component parts forming a complex/intricate whole
  - Every system is delineated by its spatial and temporal boundaries, surrounded and influenced by its environment, described by its structure and purpose and expressed in its functioning
- In engineering and physics, a physical system is the portion of the universe that is being studied (of which a thermodynamic system is one major example)
- An **open** system exchanges matter and energy with its surroundings. A **closed** system exchanges energy, but not matter, with its environment; like Earth. An **isolated** system exchanges neither matter nor energy with its environment

http://www.merriam-webster.com/dictionary/system
Citation: Pidwirny, M. (2006). "Definitions of Systems and Models".
http://www.physicalgeography.net/fundamentals/4b.html

What is a System?

- **Systems**
  - a group of interacting parts that work to together to do a job or to form a whole
    - Open Systems
    - Closed Systems

What is a System?

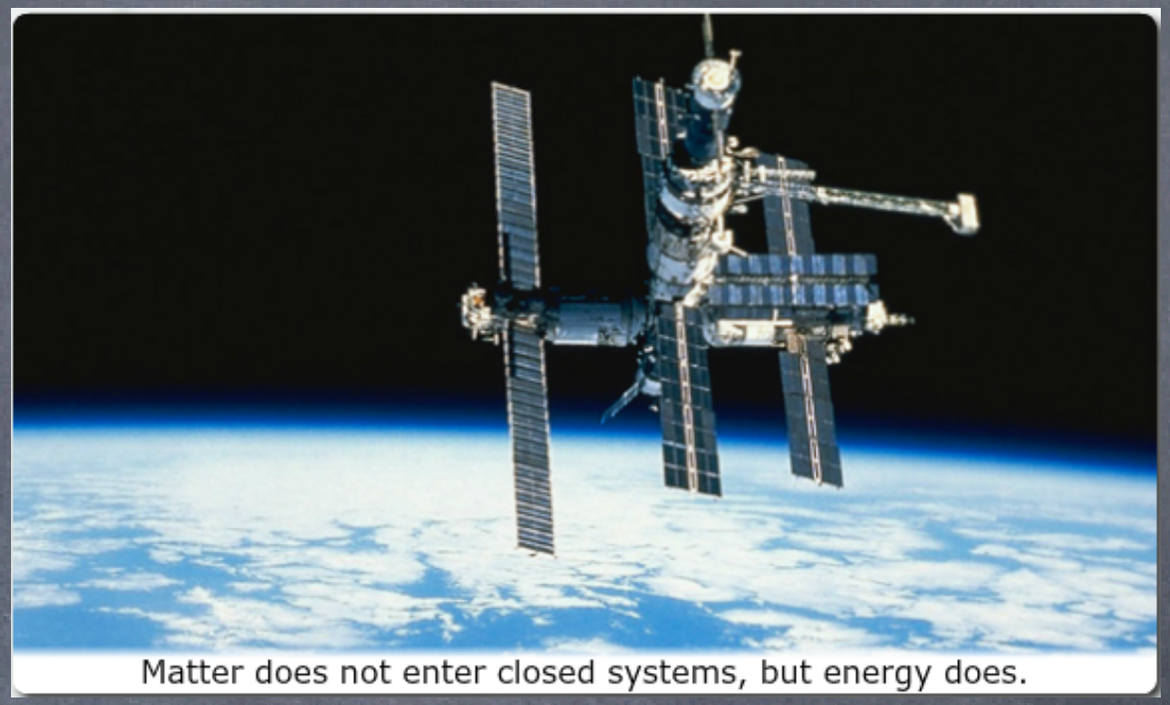
- Systems
  - Open System
    - Matter and energy can flow into and out of the system
      - Uncovered pan of boiling water
      - Vegetable Garden
      - Natural Environment

A car is an open **system**. Matter and energy move in.

Matter and energy move out of an open system.

What is a System?

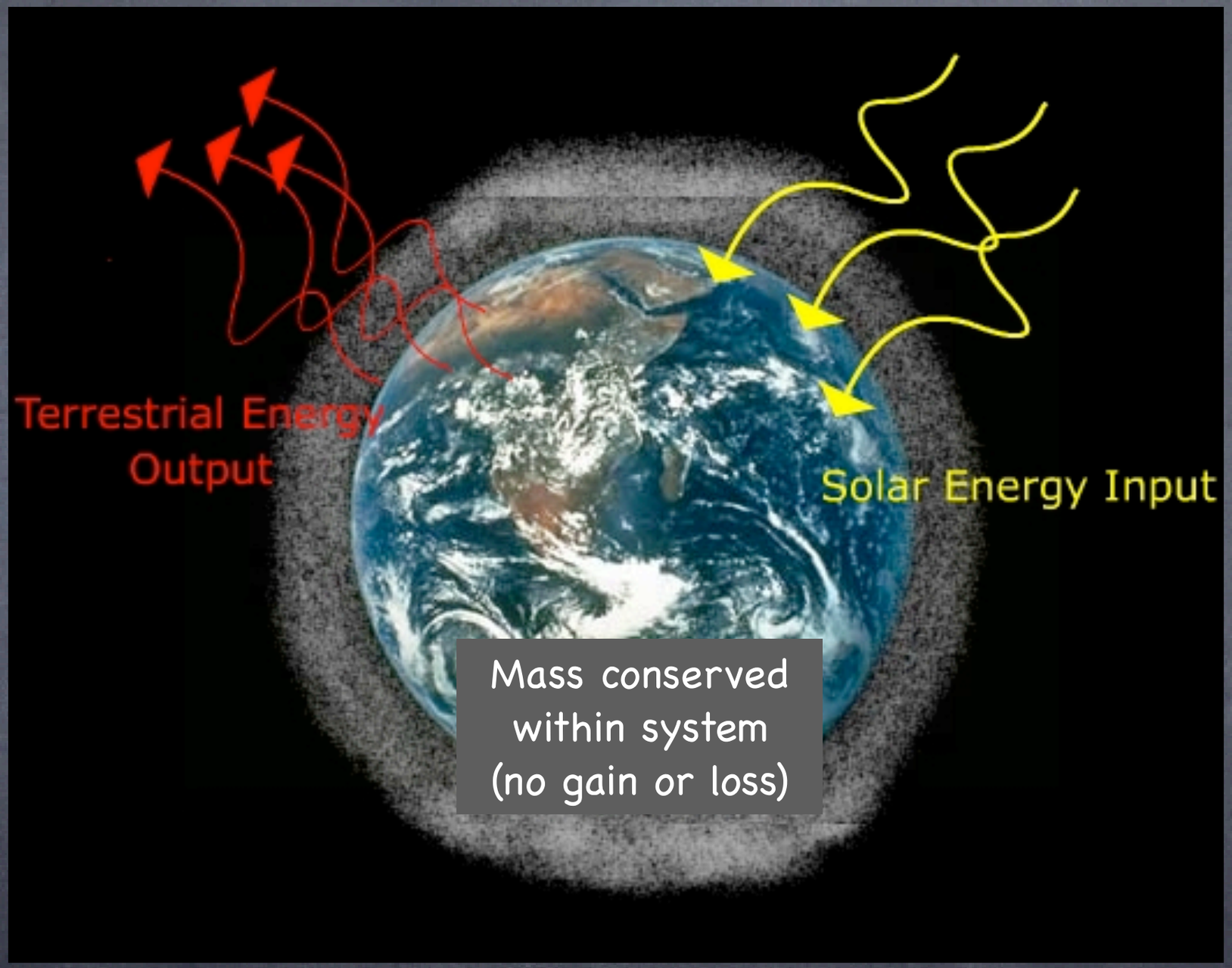
- Systems
  - Closed System
    - Matter cannot enter or leave, energy can
      - Covered pan of boiling water
  - Terrarium
  - Greenhouse



Matter does not enter closed systems, but energy does.

Matter moves around inside closed systems. Energy moves out.

Earth as a closed System



Closed system: exchange of energy but negligible exchange of mass with surroundings

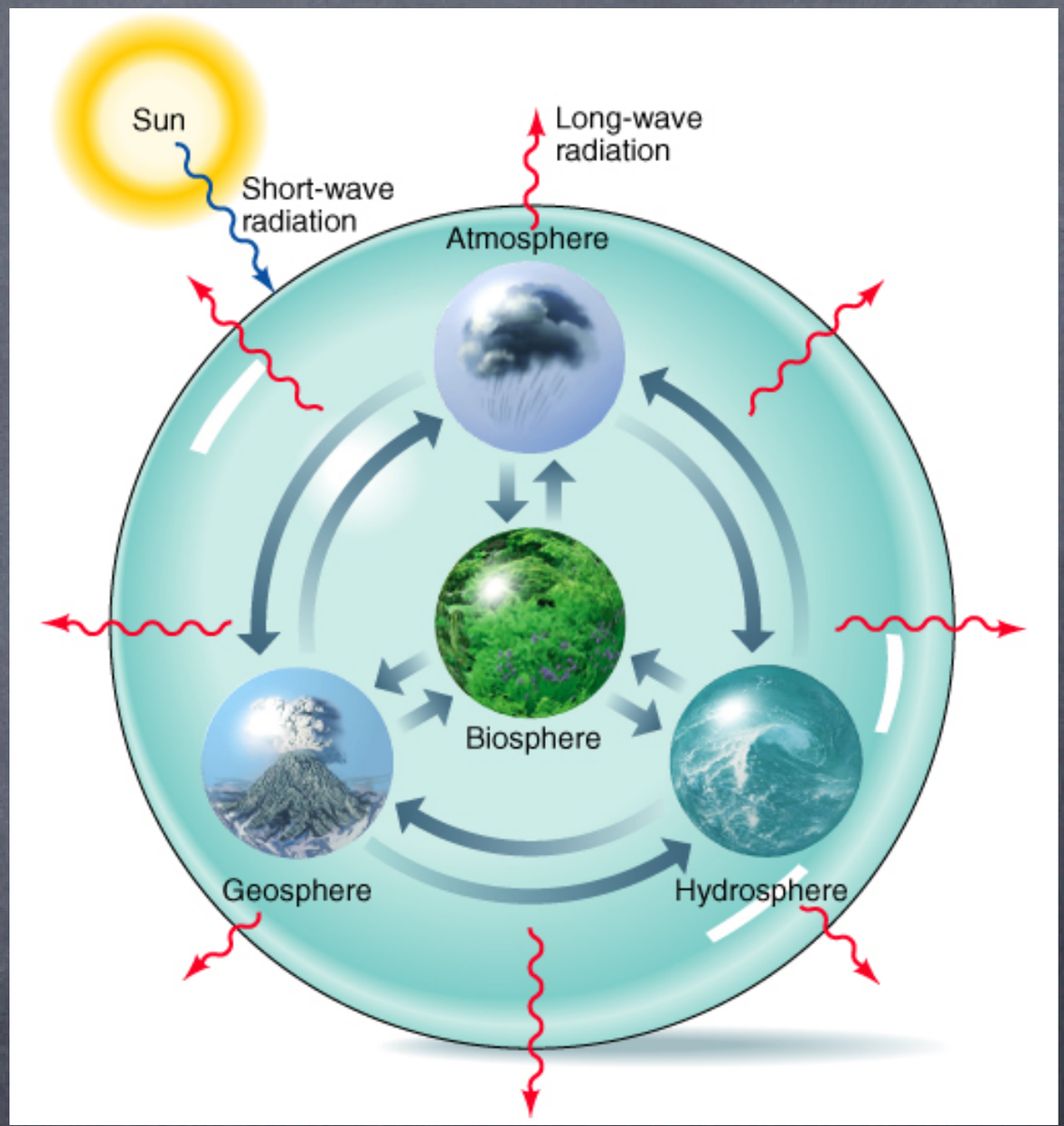
Earth System Physics

- Study the processes and interactions (cycles) among the **atmosphere**, **hydrosphere**, cryosphere, biosphere, and **geosphere** from a global to local point-of-view, and across the time scales (minutes to eons) in which these spheres interact.
- It requires the use of **physical** and chemical laws with mathematics to describe the physical, chemical and biological processes within each sphere and the interactions between the spheres.
- These descriptions are used along with observations to construct **models** through which complex interactions of the spheres are studied.
- It is through the understanding of these complex interactions that accurate, **predictive** models are developed.

Earth System

Earth System

- A **complex** system made up of:
  - **Matter**
    - Living Things
    - Nonliving things.
  - **Energy**
  - **Processes** within Earth's
    - Matter and energy continuously cycled through the smaller systems that make up Earth's spheres.



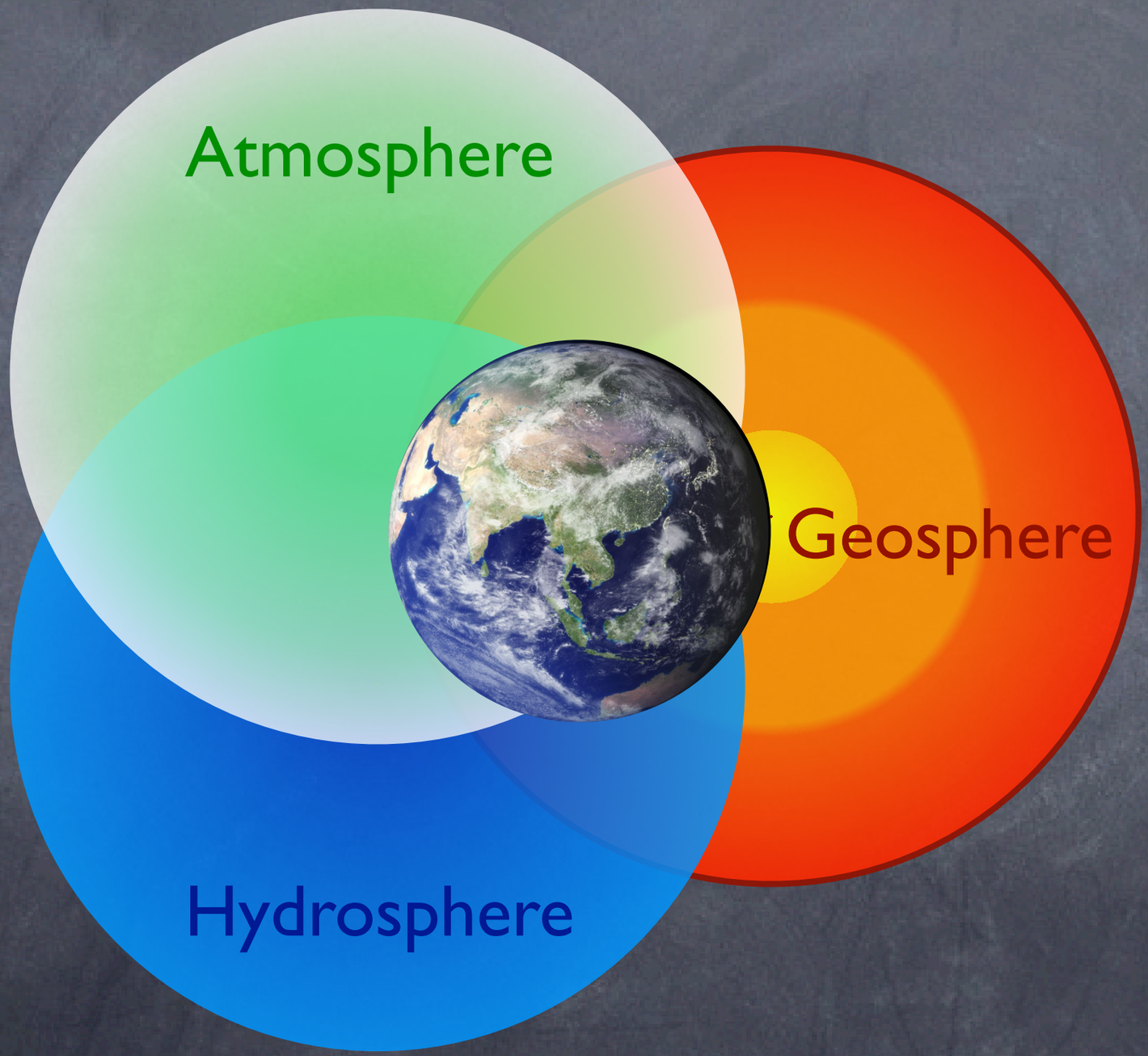
Major Themes

Scale Processes in the Earth system act on length scales of microns to thousands of kilometers, and on time scales of milliseconds to millions of years.

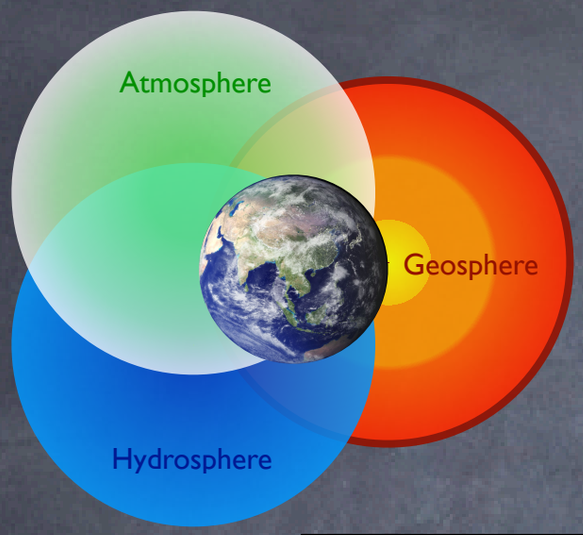
Energy The Earth system is powered by one external source (the Sun) and two internal ones: radioactive decay, and gravitational energy (heat still being lost from planetary formation).

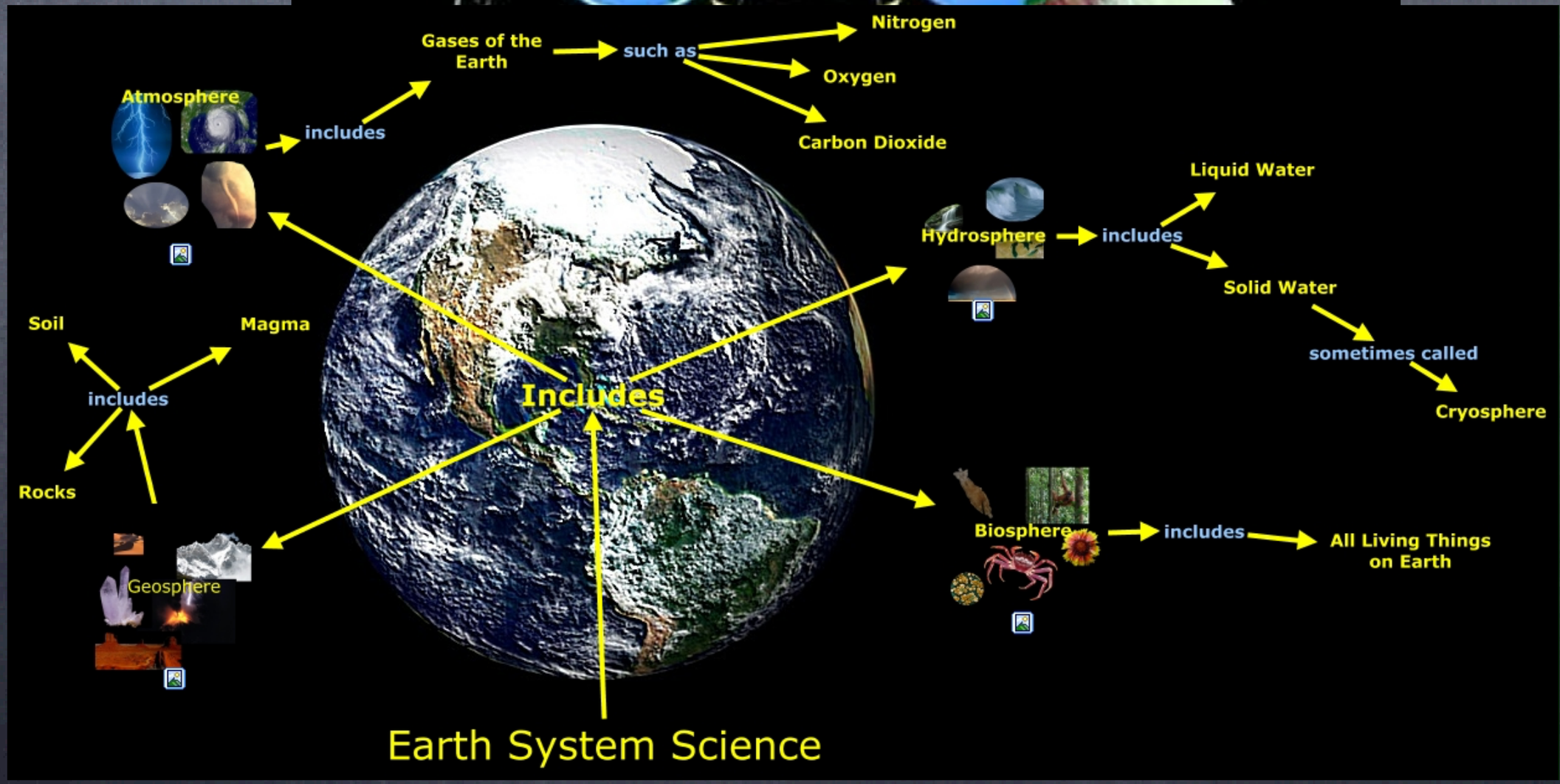
Cycles Material in the Earth system is continually recycled in numerous overlapping cycles.

Earth System



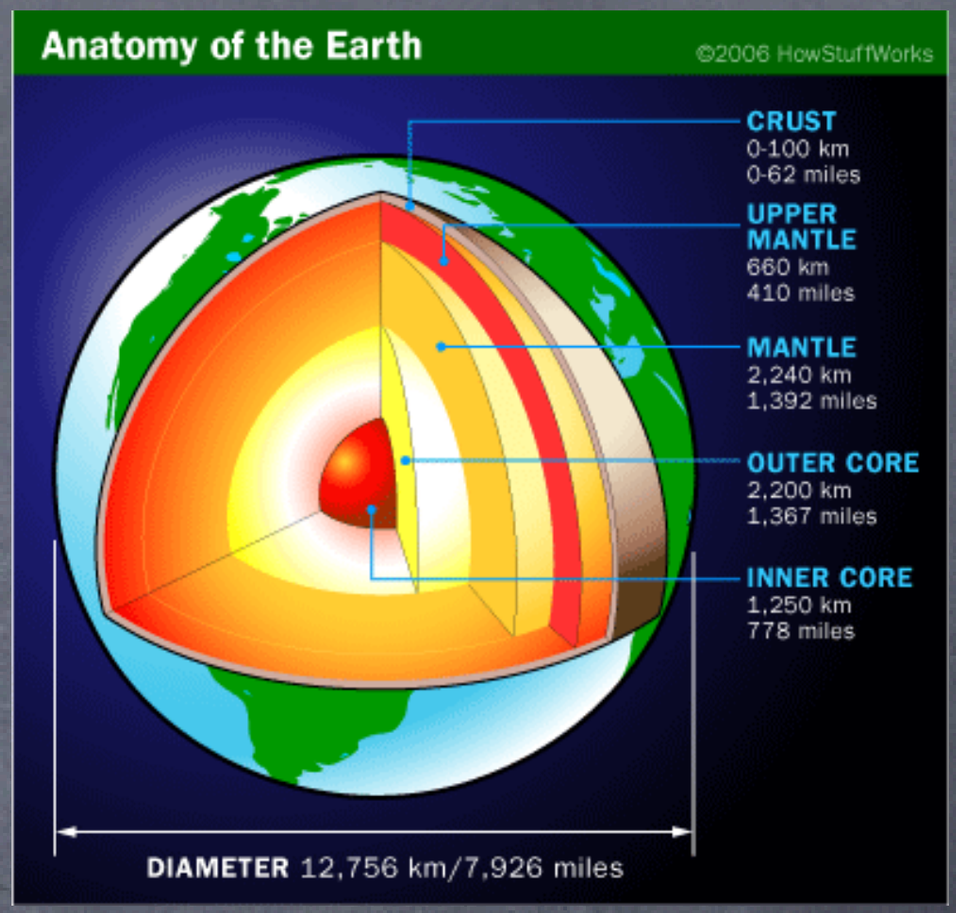
Earth system





What is the Earth's Geosphere?

- **Geosphere**
  - Mostly solid, rocky part of the Earth.
  - Divided into 3 Layers
    - 1. Crust
    - 2. Mantle
    - 3. Core
      - a. Inner Core
      - b. Outer Core



What is the Earth's Hydrosphere?

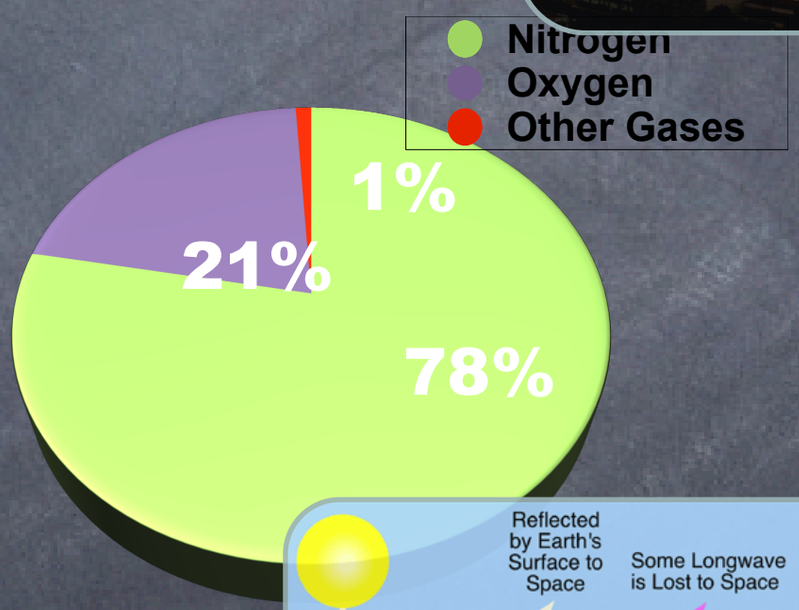
- **Hydrosphere**
  - Part of the Earth that is liquid water.
  - Always moving, through all spheres.
  - 71% of Earth's surface is the ocean.
    - Lakes, Rivers, Marshes
    - Rain
    - Underground water
    - Droplets in clouds.

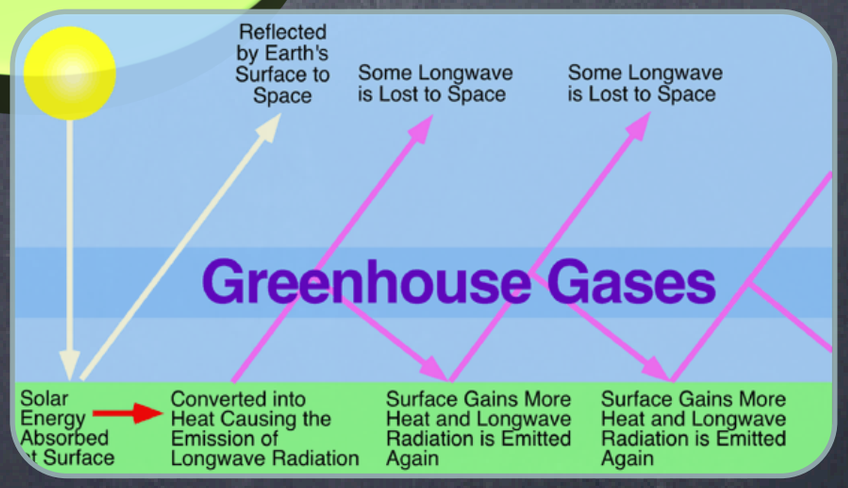
What is the Earth's Cryosphere?

- **Cryosphere**
  - Made up of all frozen water on Earth.
    - Ice
    - Sea Ice
    - Glaciers
    - Ice Shelves
    - Ice Bergs
    - Snow

What is the Earth's Atmosphere?

- **Atmosphere**
  - Mostly made of invisible gases that surround the Earth
  - Contains the air we breathe
  - Composition
    - 71% Nitrogen
    - 23% Oxygen
    - 1% Trace Gases
- Traps Heat Energy from the sun
  - Greenhouse effect, keeps the planet warm



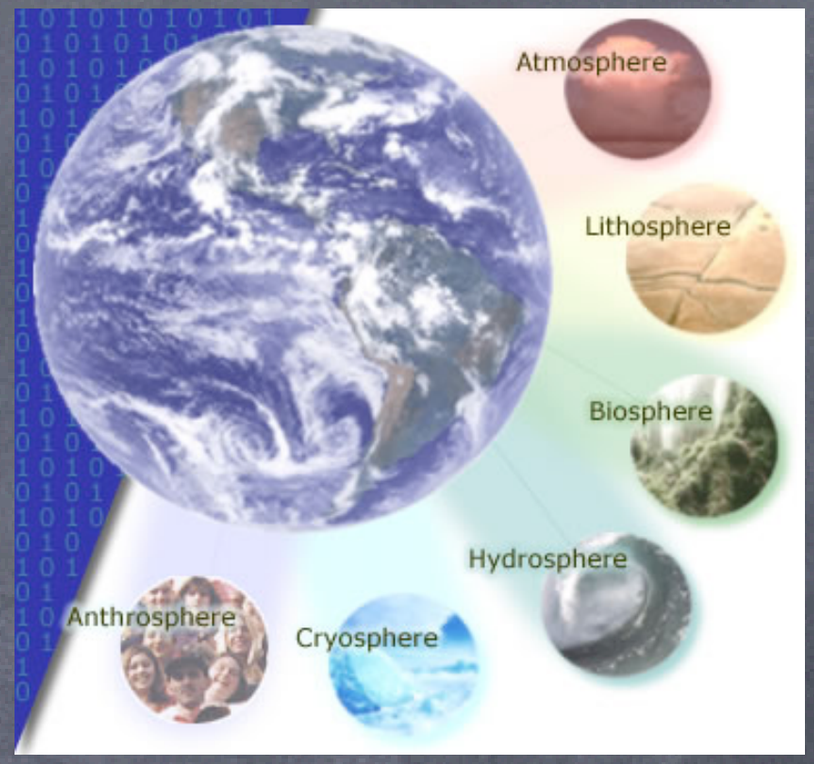


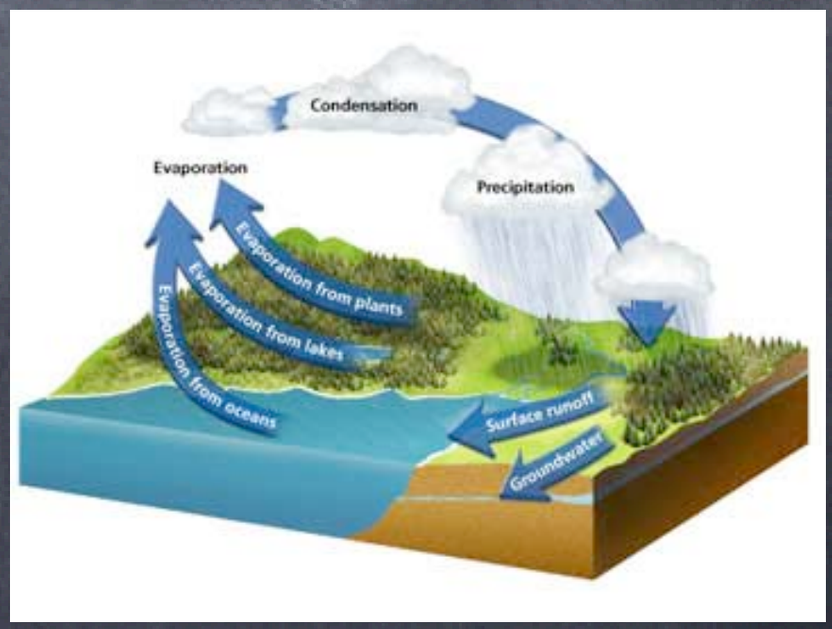
What is the Earth's Biosphere?

- **Biosphere**
  - Made up of living things and their habitats
  - Must Have:
    - Oxygen
    - Carbon Dioxide
    - Liquid Water
    - Moderate Temperatures
    - Source of Energy
      - Sun
      - Plants and Algae (photosynthesis)

How Do Earth's Spheres Interact?

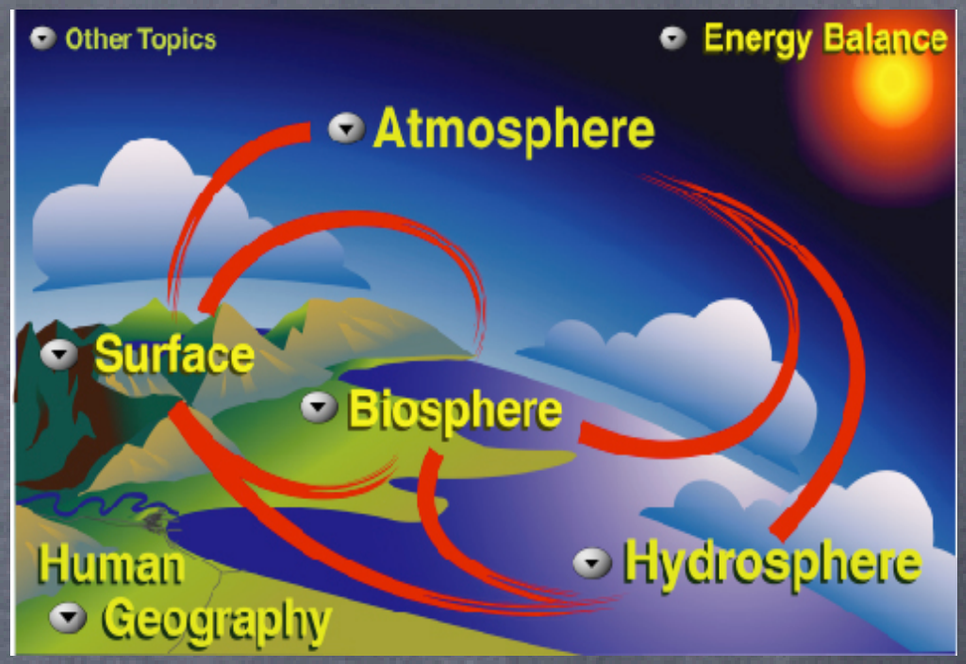
- **Matter and Energy**
  - 1. By exchange of matter
    - Water Cycle
      - Water evaporates into the atmosphere
      - Water condenses forming clouds
    - Nitrogen Cycle
      - Bacteria release nitrogen into the soil from the atmosphere
      - Plants use nitrogen to grow





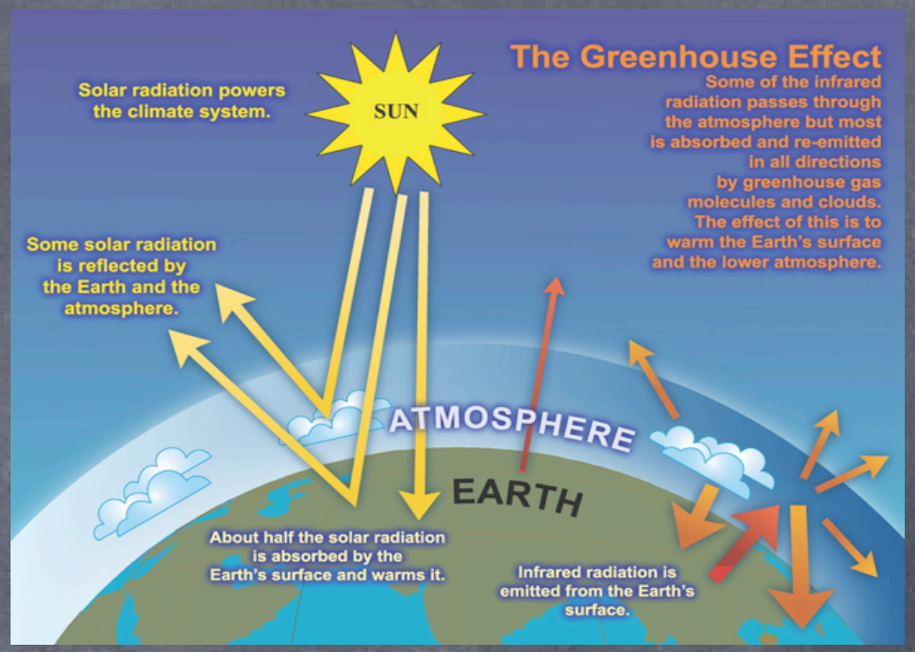
How Do Earth's Spheres Interact?

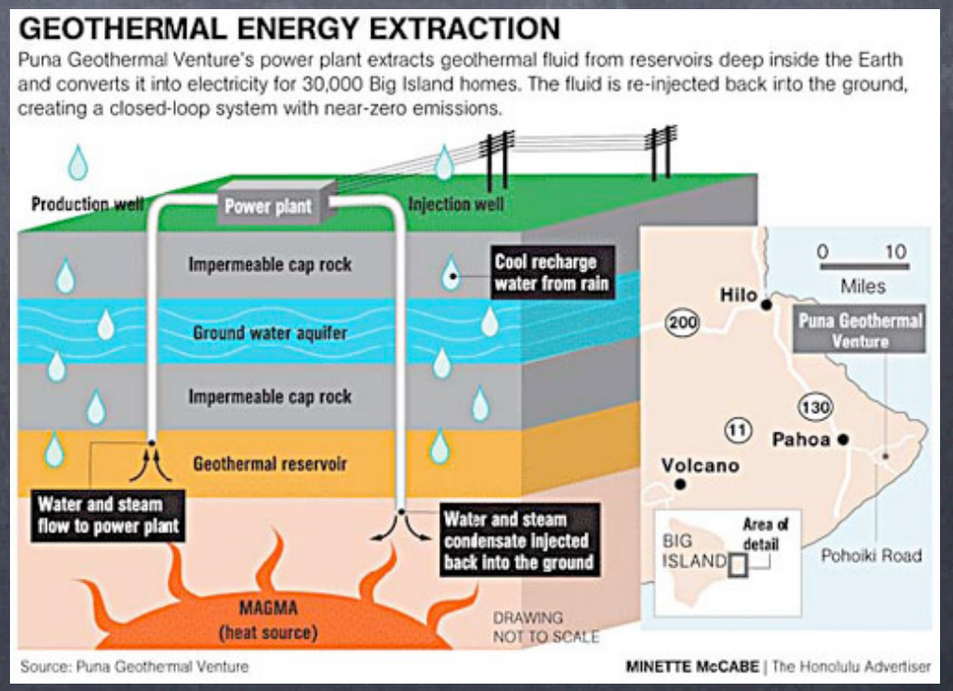
- 2. By exchange of energy
  - Moves back and forth between spheres
  - Plants use solar energy to make food
  - Animals eat plants for energy
  - Solar Energy
  - Drives winds and Weather



Source of Earth's Energy?

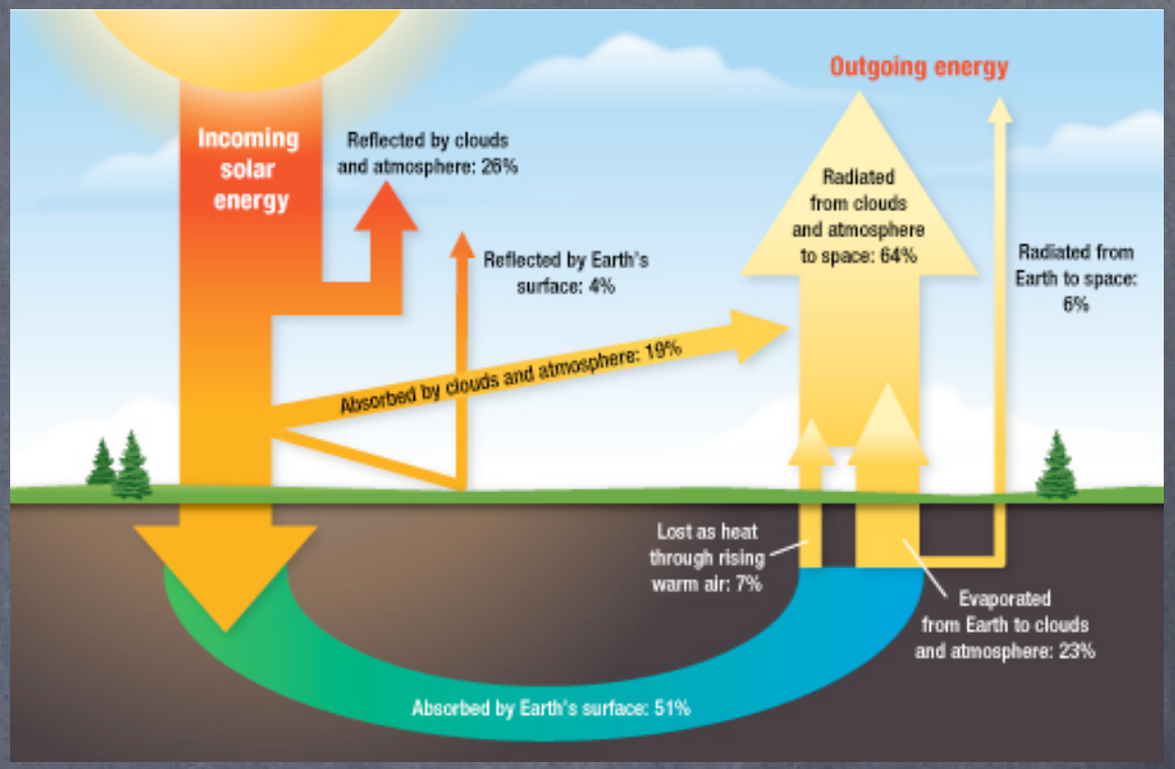
- Earth's Energy
  - Most comes from the Sun
  - A tiny fraction
    - Ocean Tides
    - Geothermal
    - Lava & Magma
  - Moves or Changes form
  - Not created or destroyed
  - Transferred between spheres





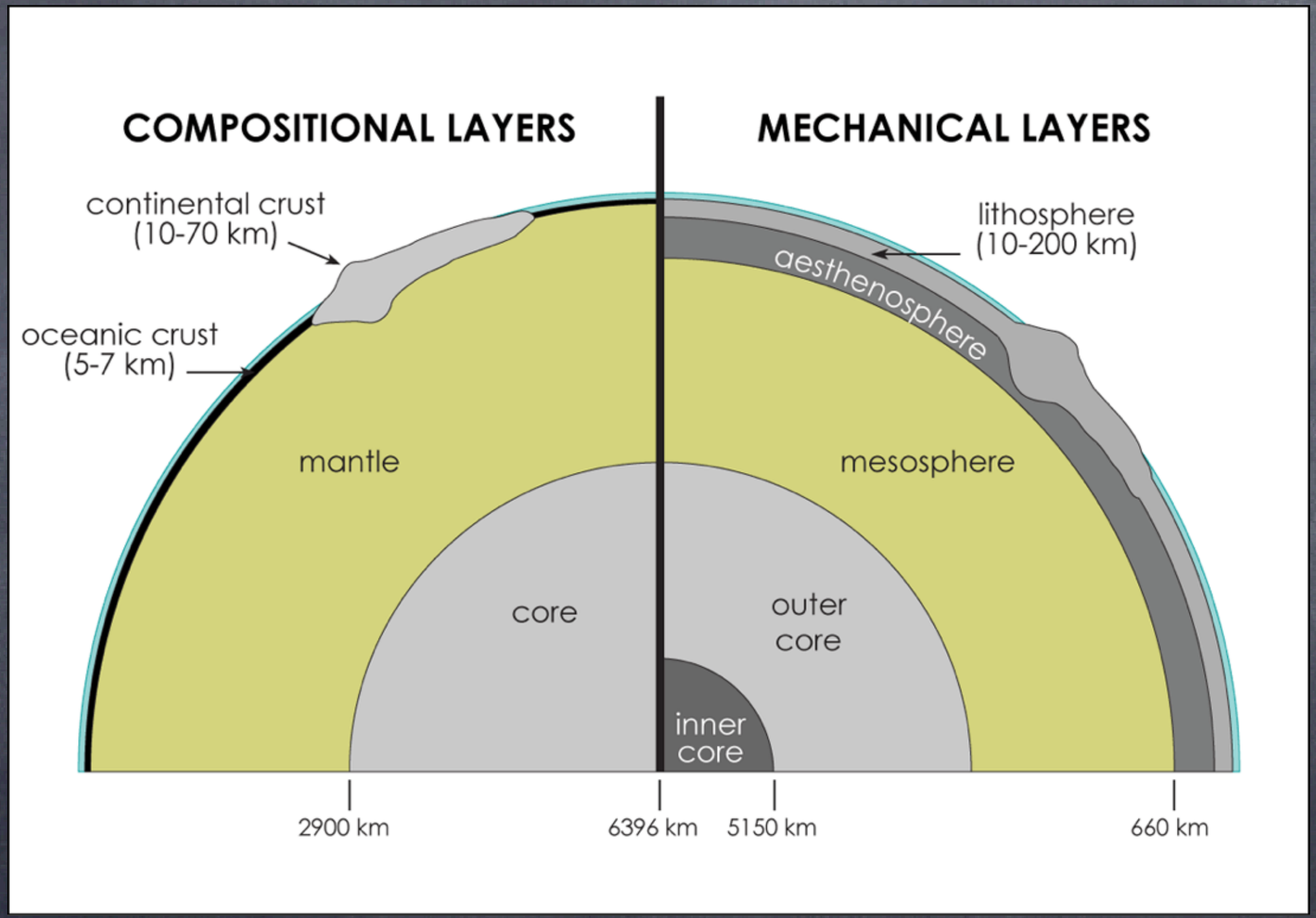
Source of Earth's Energy?

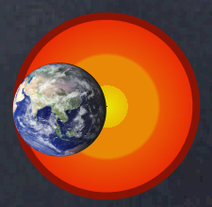
- Energy Budget
  - A way to keep track of energy transfers into and out of Earth's system



- Unbalanced budget
  - Can increase or decrease Earth's temperatures

Earth system: geosphere





Earth layers

Composition

Primarily silica plus light metallic elements →

crust

mantle

Primarily silica plus iron and magnesium →

core

Primarily iron and nickel →

Mechanical Characteristics

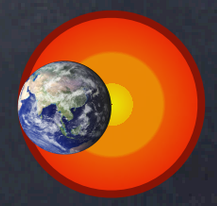
lithosphere ← brittle solid

asthenosphere ← solid (but nearly liquid)

mesosphere ← solid

outer core ← liquid

inner core ← solid



V_P V_S
ρ P
K μ

Seismic tomography

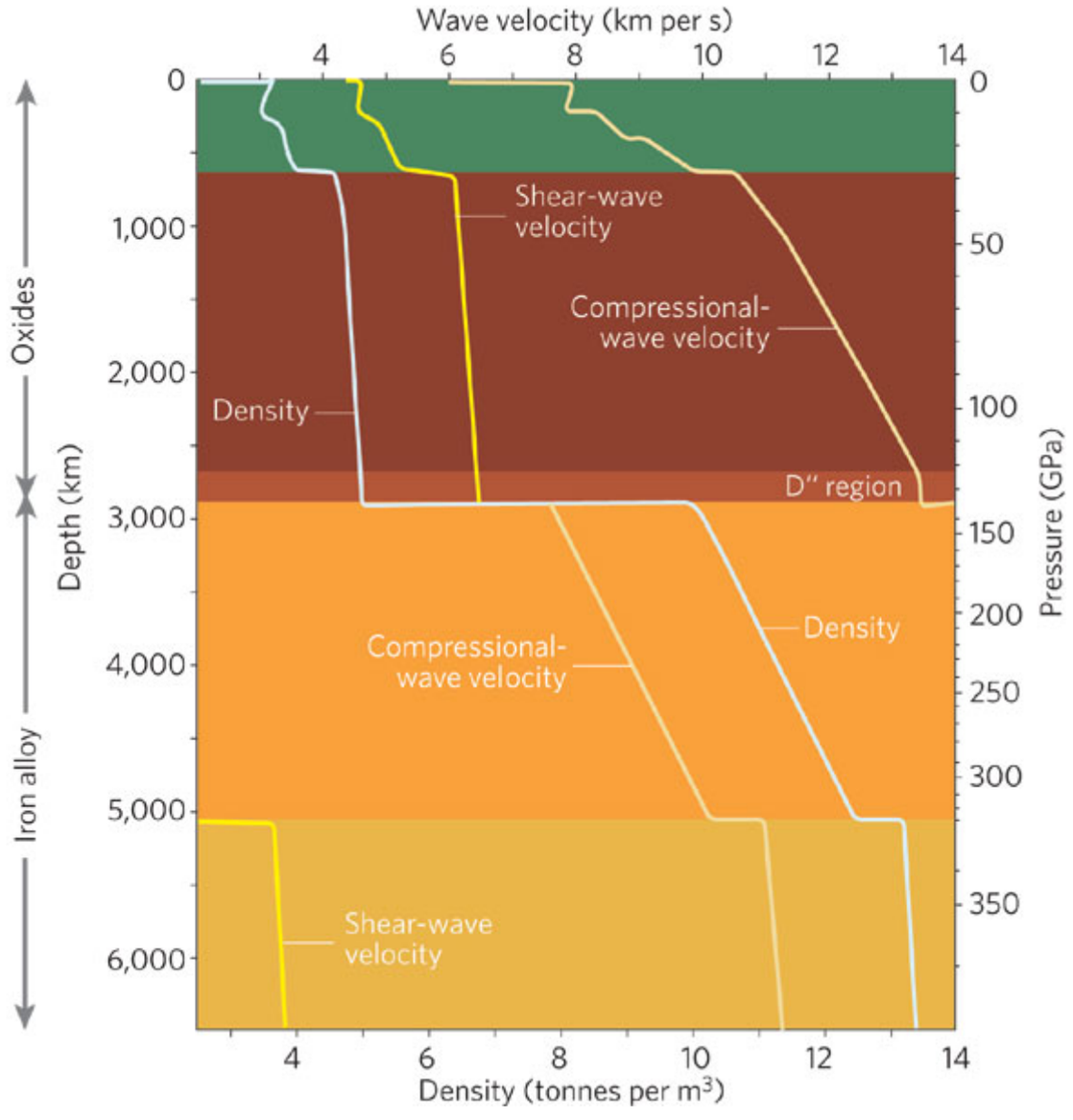
Mean density

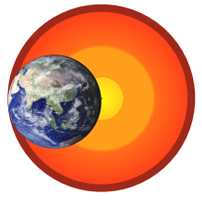
Moment of inertia

Equation of state
A-W equation
Birch's law

Seismological model

Bullen parameter





Compositional model

Mineralogy
Assemblage
Chemistry

Bulk composition

(T,P) phase diagrams

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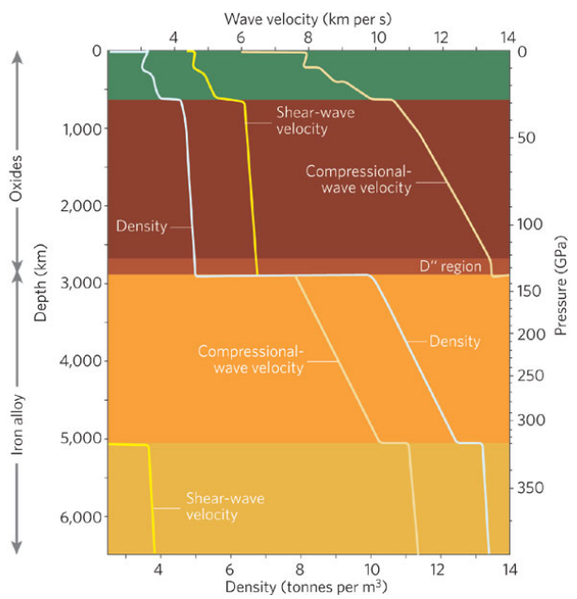

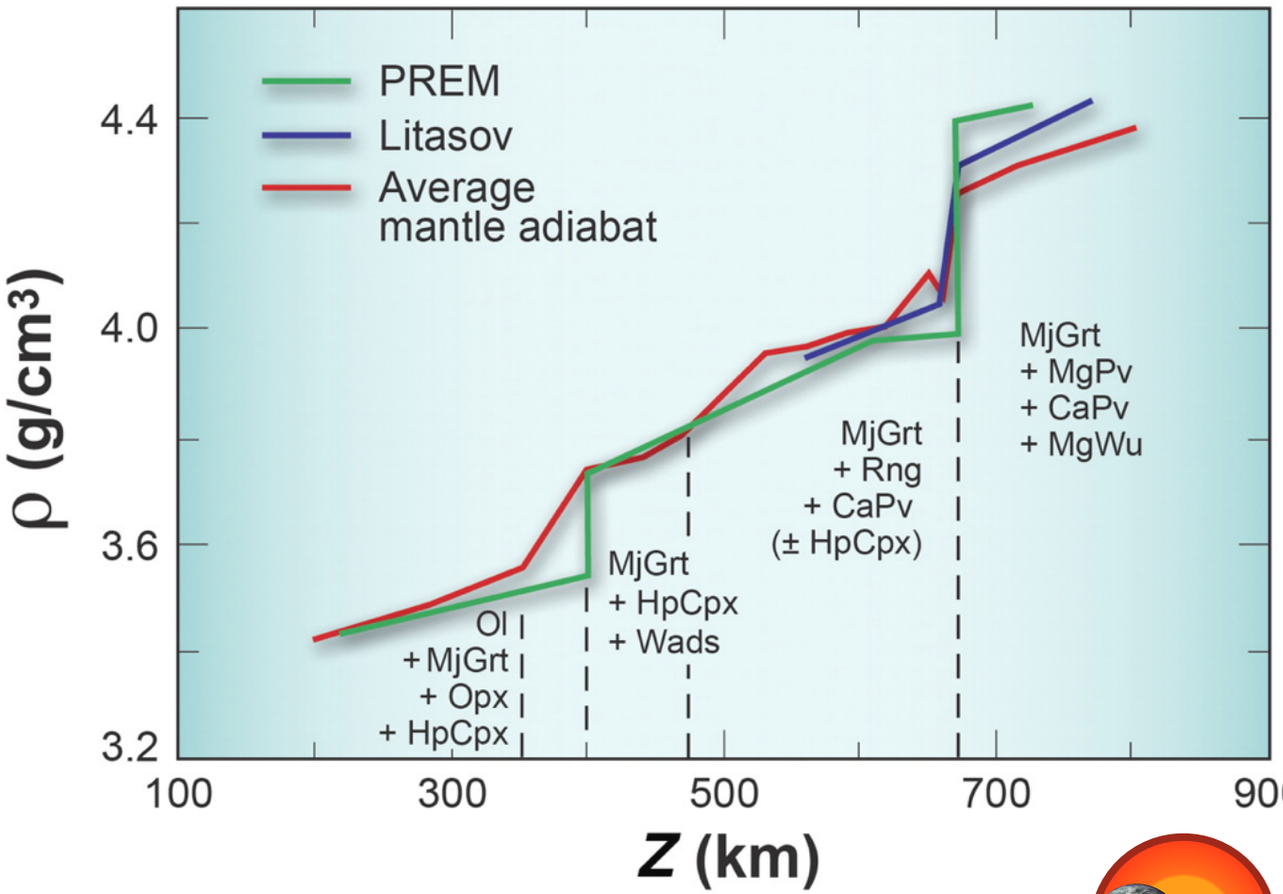

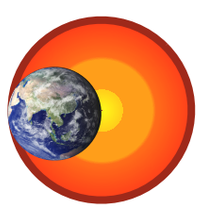

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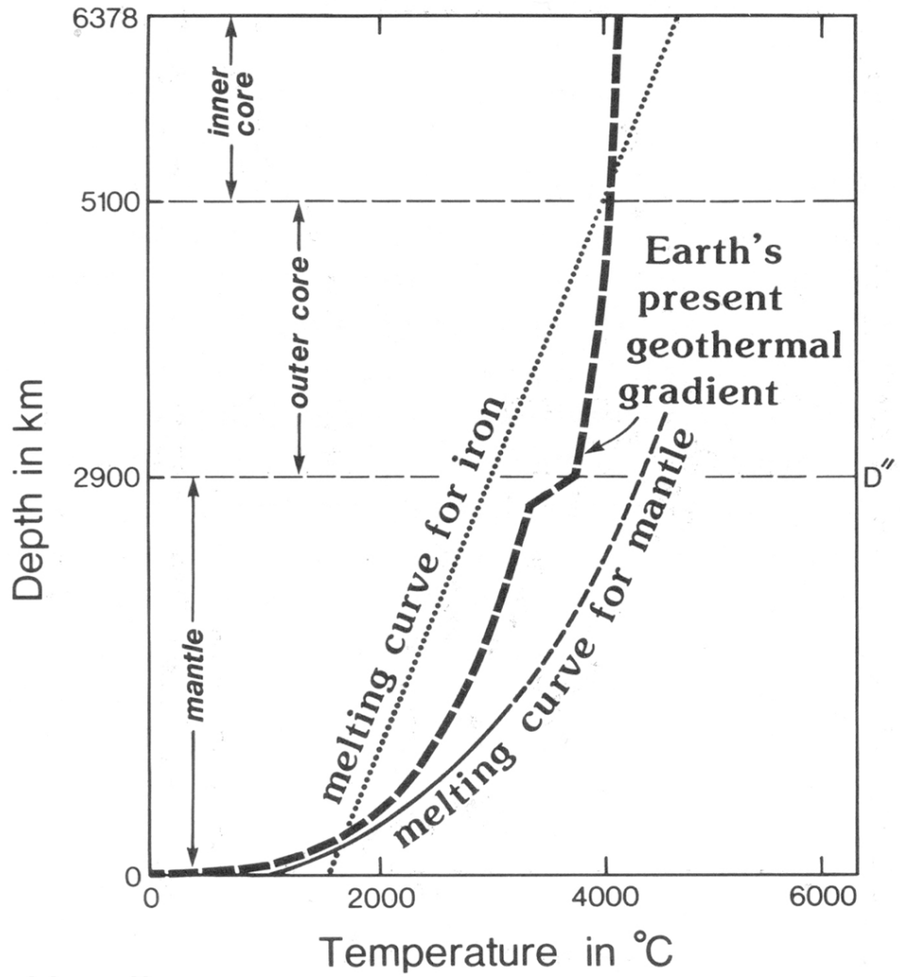
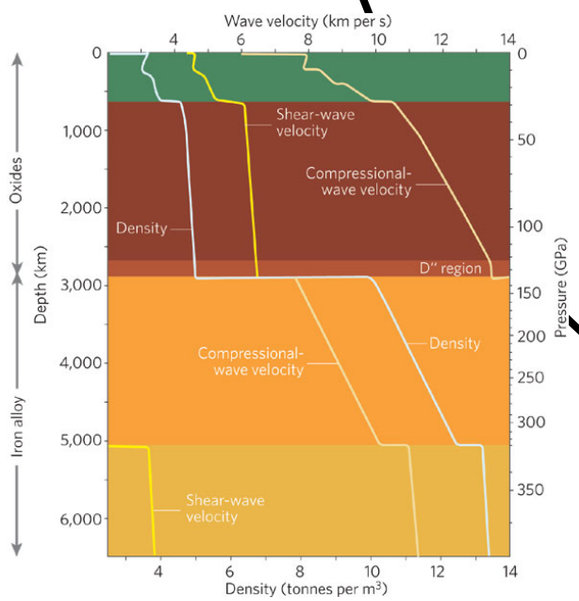




Bullen parameter

Heat flux

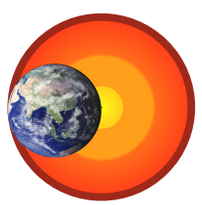
Anchoring points

Adiabatic gradient

Mantle viscosity

Thermal model

T



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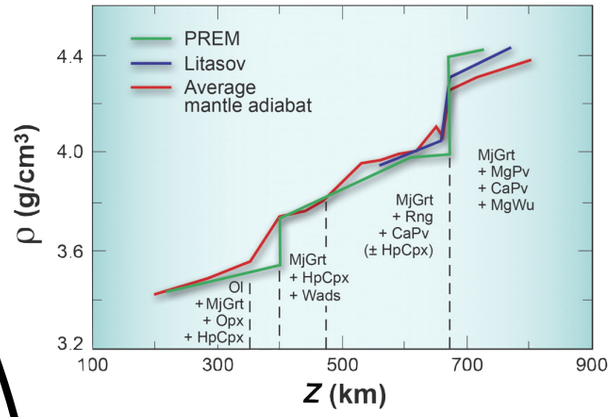

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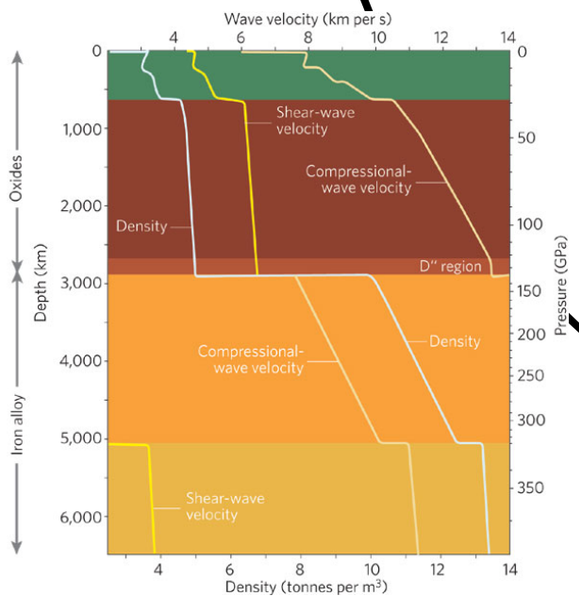

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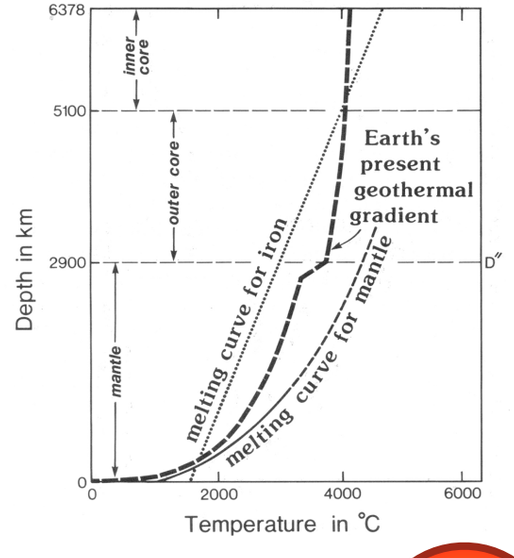
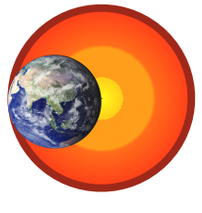
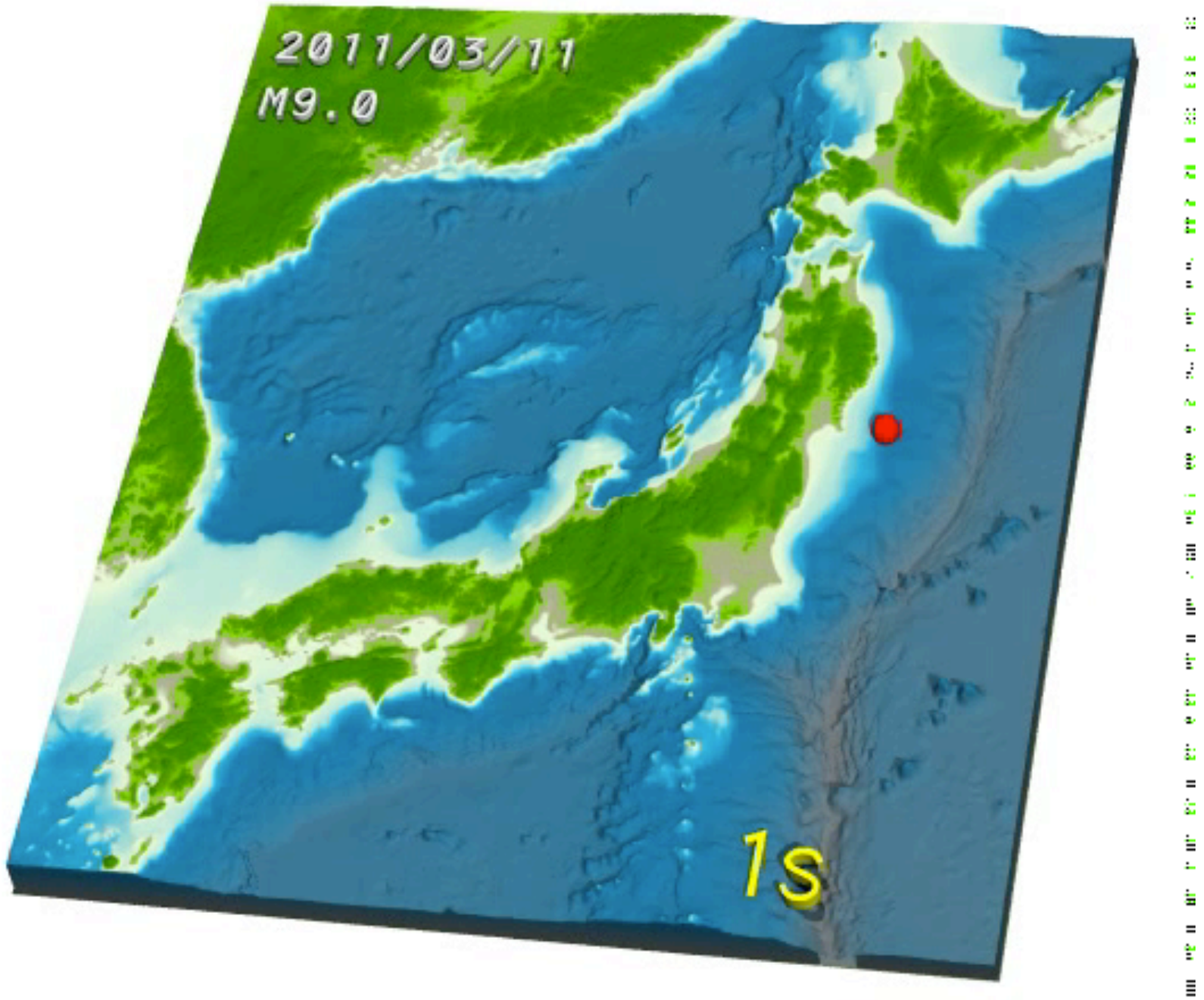




Ground motion animation: time scales...



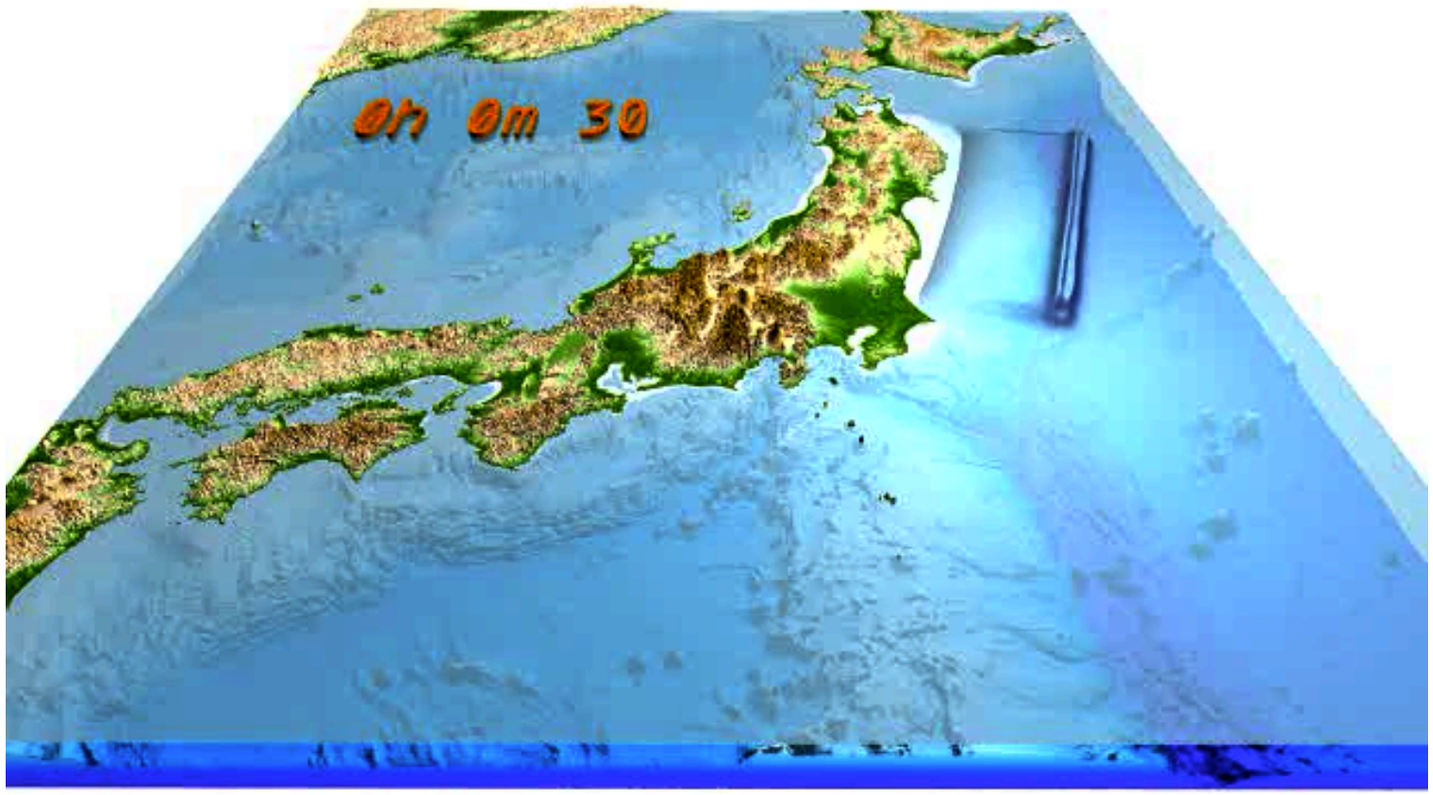
Courtesy of Takashi Furumura

Tsunami animation: time scales...

http://outreach.eri.u-tokyo.ac.jp/eqvolc/201103_tohoku/eng/

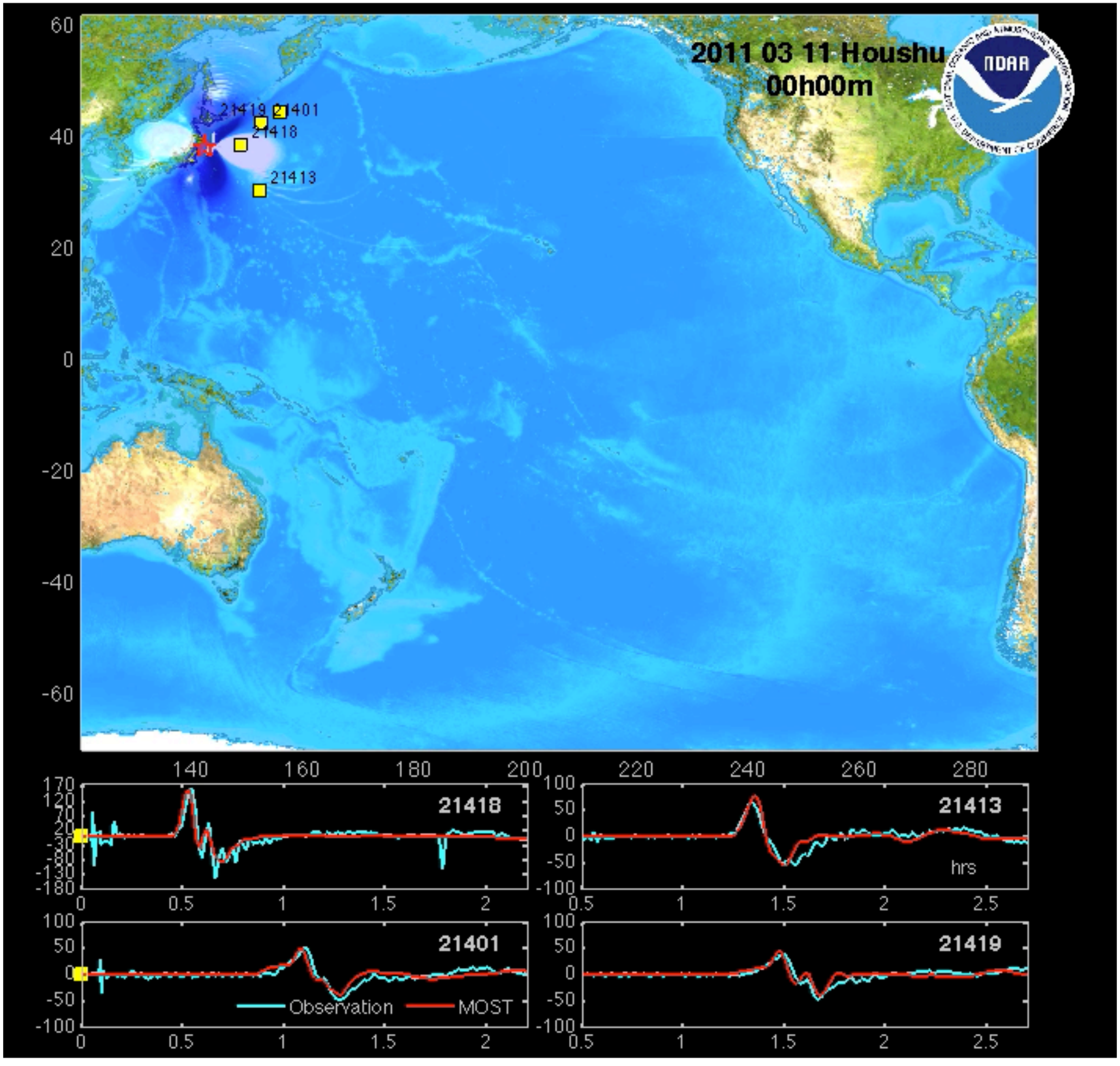
http://supersites.earthobservations.org/honshu.php

http://eqseis.geosc.psu.edu/~cammon/Japan2011EQ/



"Earthquake Research Institute, University of Tokyo, Prof. Takashi Furumura and Project Researcher Takuto Maeda"

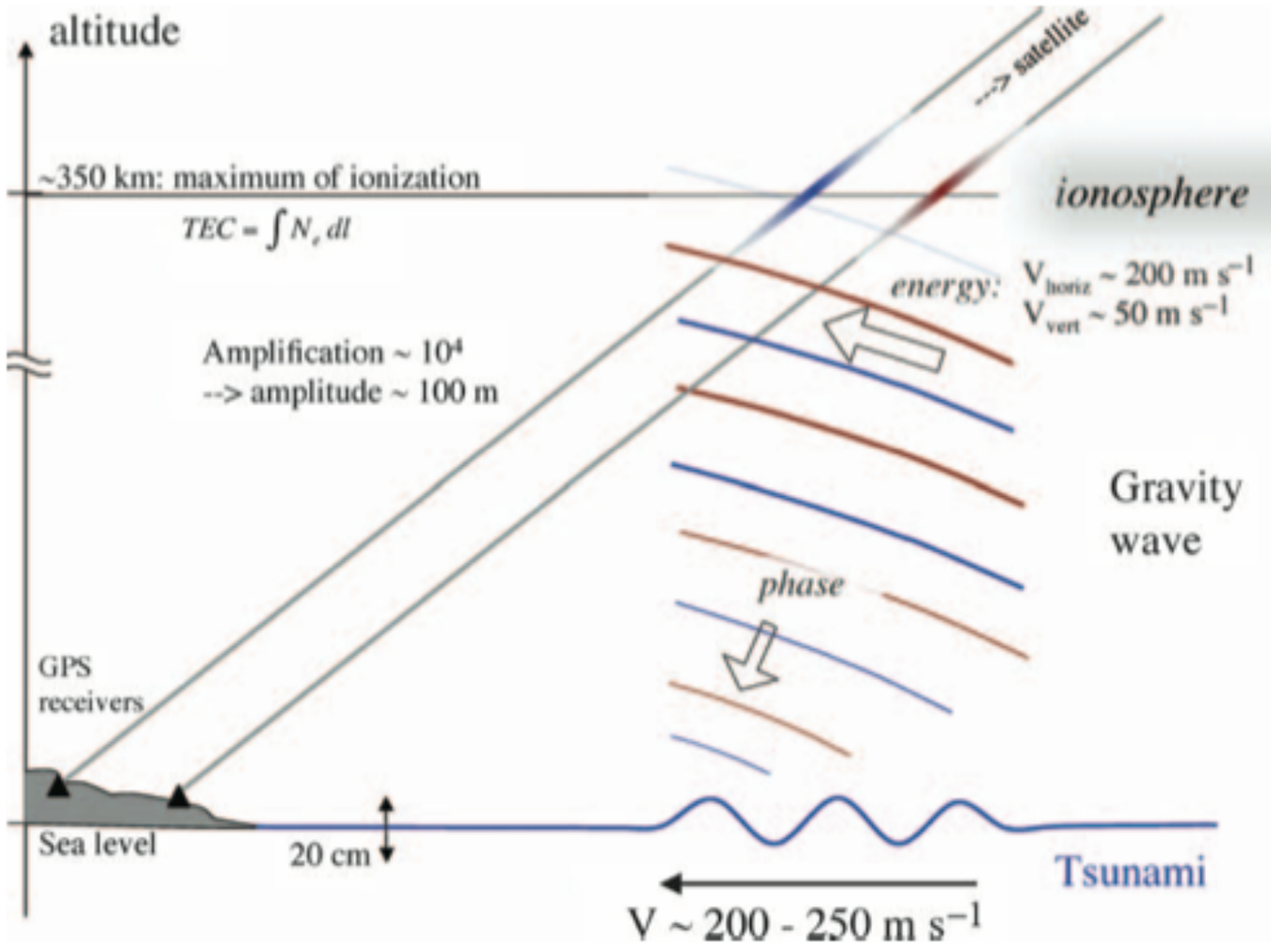
Tsunami animation - NOAA



Tsunami signature in the ionosphere

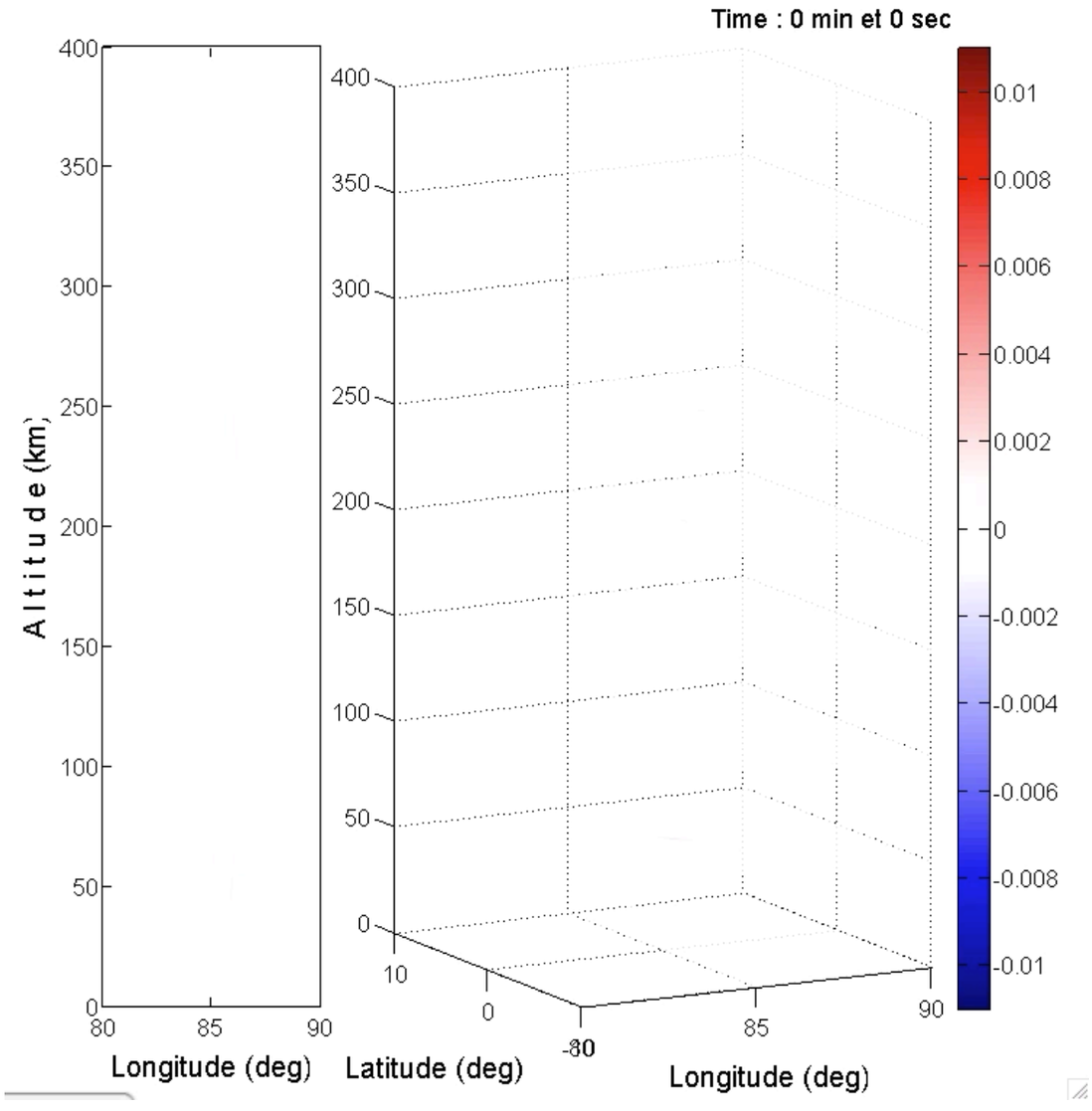
By dynamic coupling with the atmosphere, acoustic-gravity waves are generated

Traveling Ionospheric Disturbances (TID) can be detected and monitored by high-density GPS networks

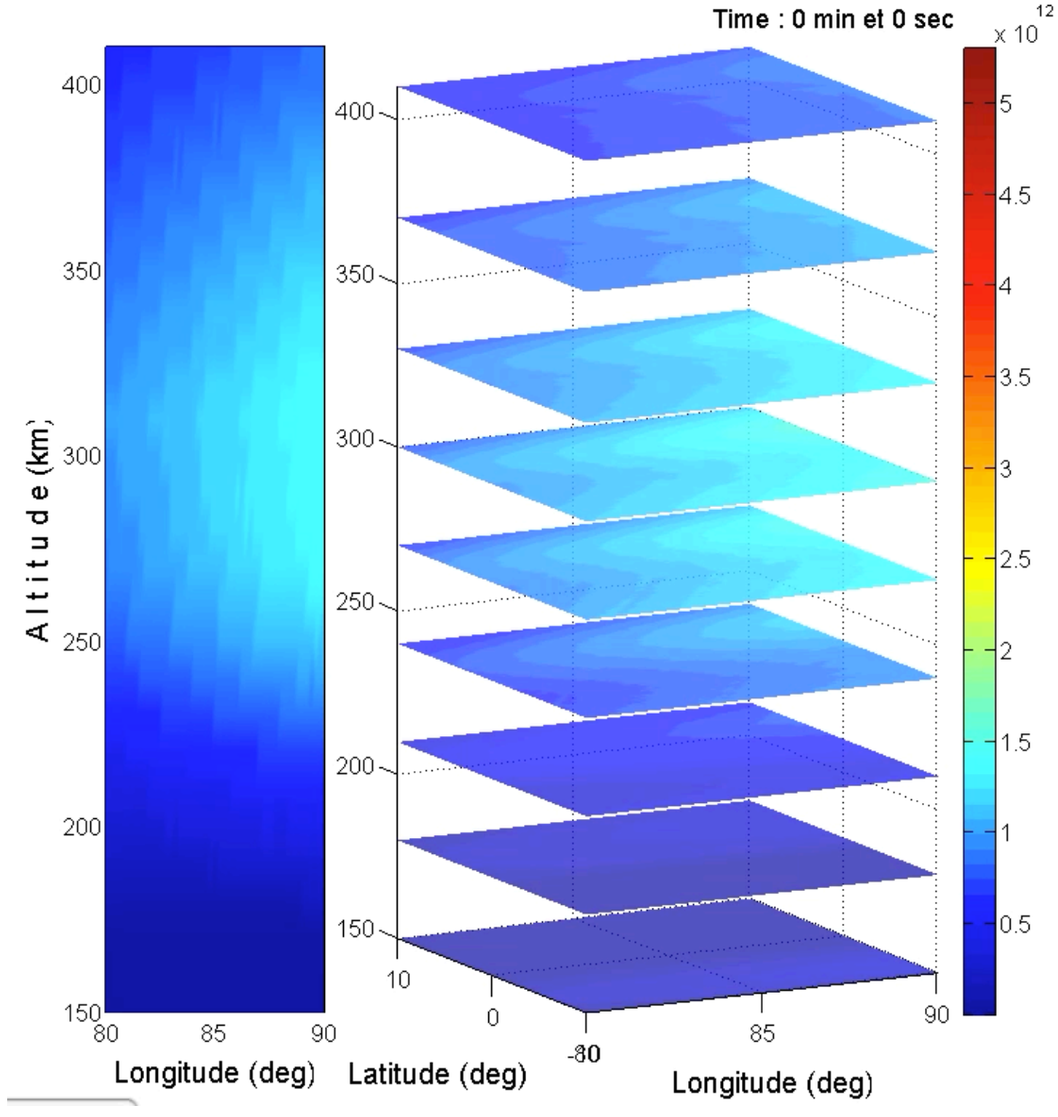


Tsunami signature in the ionosphere

Tsunami-generated IGWs and the response of the ionosphere to neutral motion at 2:40 UT.



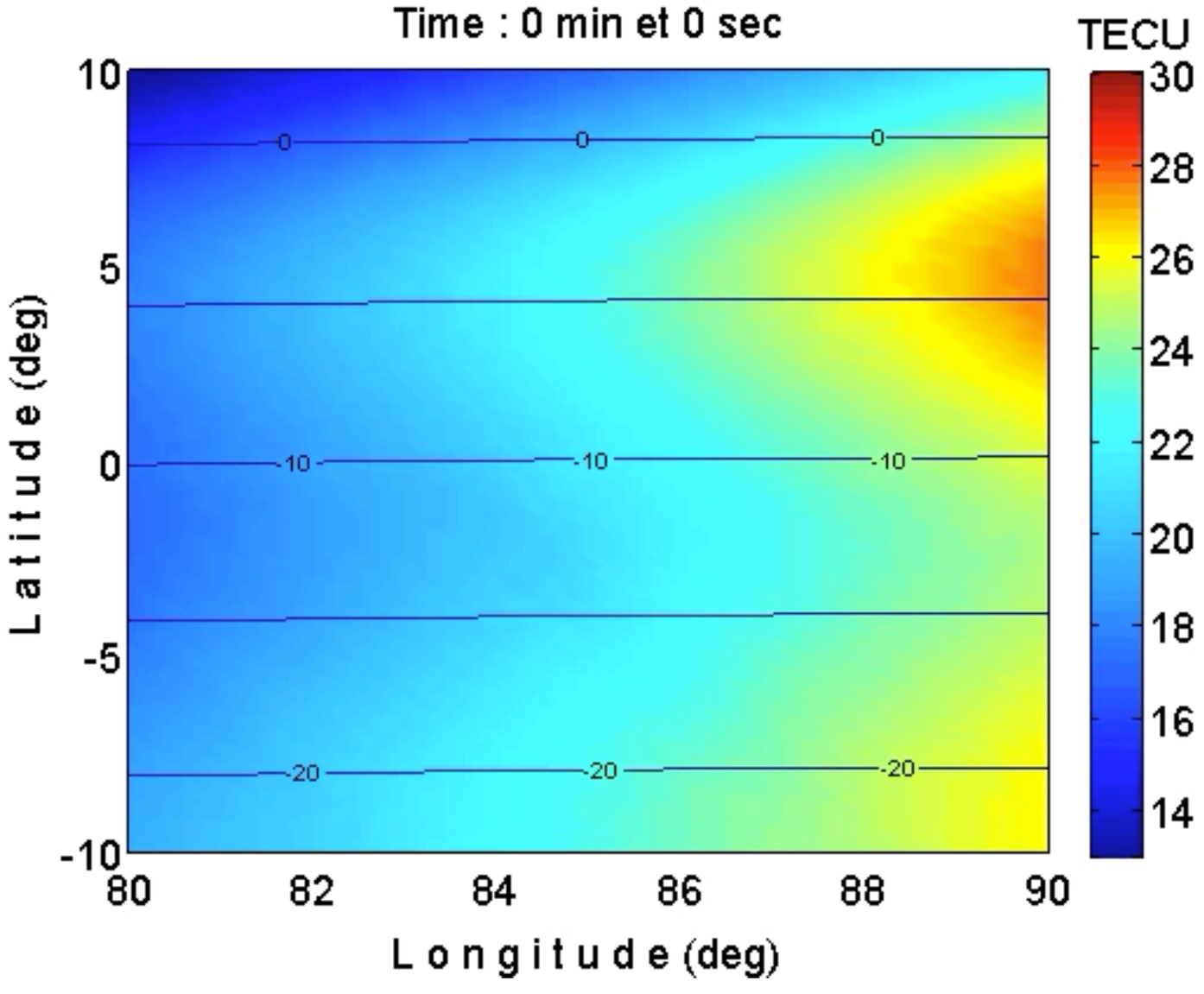
Normalized vertical velocity



Perturbation in the ionospheric plasma

Tsunami signature in the ionosphere

- The TEC (Total Electron Content) perturbation induced by tsunami-coupled IGW is superimposed on a broad local-time (sunrise) TEC structure.



Mathematical reference: PDEs

Classification of Partial Differential Equations (PDE)

Second-order PDEs of two variables are of the form:

$$a\frac{\partial^2 f(x,y)}{\partial x^2} + b\frac{\partial^2 f(x,y)}{\partial x \partial y} + c\frac{\partial^2 f(x,y)}{\partial y^2} + d\frac{\partial f(x,y)}{\partial x} + e\frac{\partial f(x,y)}{\partial y} = F(x,y)$$

$b^2 - 4ac < 0$	elliptic	LAPLACE equation
$b^2 - 4ac = 0$	parabolic	DIFFUSION equation
$b^2 - 4ac > 0$	hyperbolic	WAVE equation

Elliptic equations produce **stationary and energy-minimizing** solutions

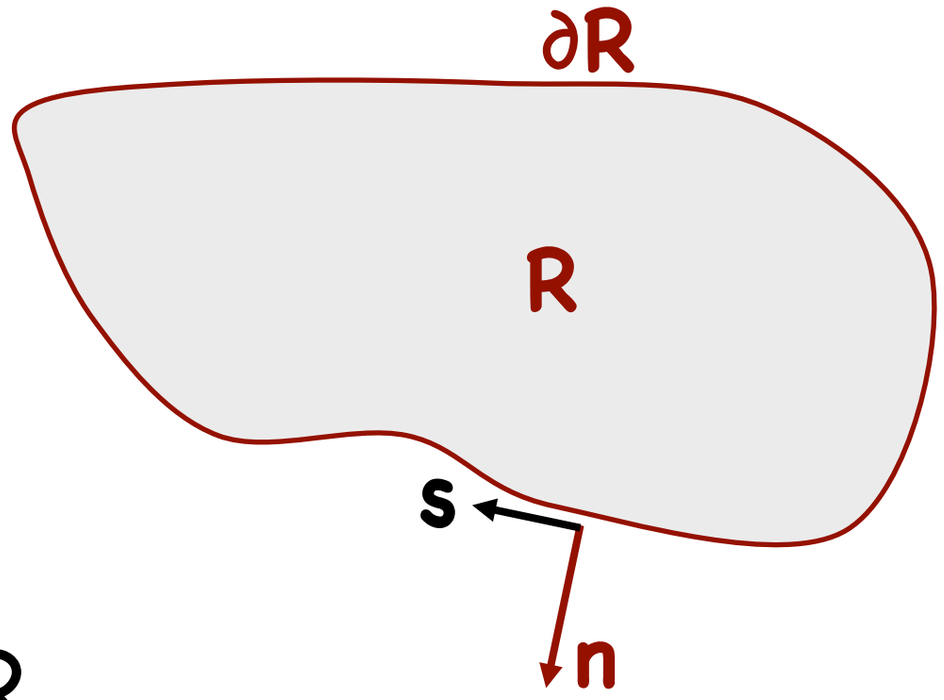
Parabolic equations a **smooth-spreading flow** of an initial disturbance

Hyperbolic equations a **propagating disturbance**

Boundary and Initial conditions

Initial conditions: starting point for propagation problems

Boundary conditions: specified on domain boundaries to provide the interior solution in computational domain



Dirichlet: $u = f$ on ∂R

Neumann: $\frac{\partial u}{\partial n} = f$ or $\frac{\partial u}{\partial s} = g$ on ∂R

Robin: $\frac{\partial u}{\partial n} + ku = f$ on ∂R

Elliptic PDEs

Steady-state two-dimensional **heat conduction** equation is prototypical **elliptic PDE**

Laplace equation - no heat generation

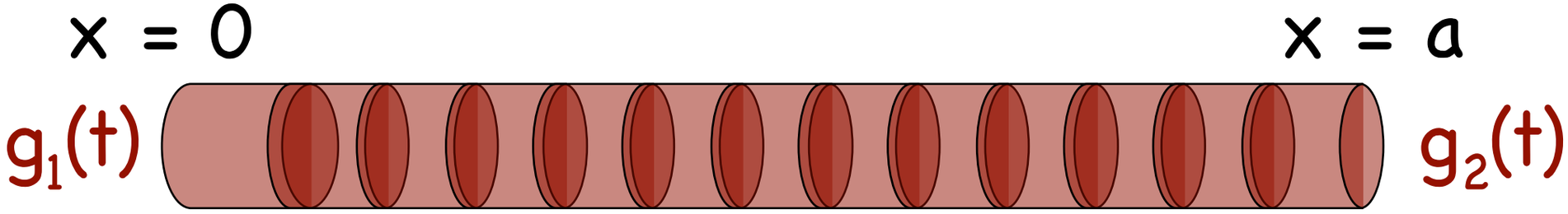
$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0$$

Poisson equation - with heat source

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = f(x, y)$$

Parabolic PDE

Heat transfer in a one-dimensional rod



$$\frac{\partial u}{\partial t} = d\,\frac{\partial^2 u}{\partial x^2} \qquad 0 \le x \le a, \quad 0 \le t \le T$$

I.C.s $\quad u(x,0) = f(x) \qquad 0 \le x \le a$

B.C.s $\quad \begin{cases} u(0,t) = g_1(t) \\ u(a,t) = g_2(t) \end{cases} \qquad 0 \le t \le T$

Hyperbolic PDE: wave equation

$b^2 - 4ac = 0 - 4(1)(-c^2) > 0$: Hyperbolic

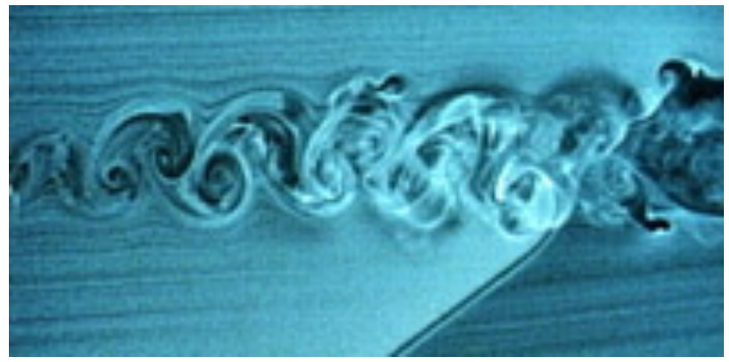
$$\frac{\partial^2 u}{\partial t^2} = v^2 \frac{\partial^2 u}{\partial x^2} \qquad 0 \le x \le a, \quad 0 \le t$$

$$\text{I.C.s} \quad \begin{cases} u(x,0) = f_1(x) \\ u_t(x,0) = f_2(x) \end{cases} \qquad 0 \le x \le a$$

$$\text{B.C.s} \quad \begin{cases} u(0,t) = g_1(t) \\ u(a,t) = g_2(t) \end{cases} \qquad t > 0$$

Coupled PDE

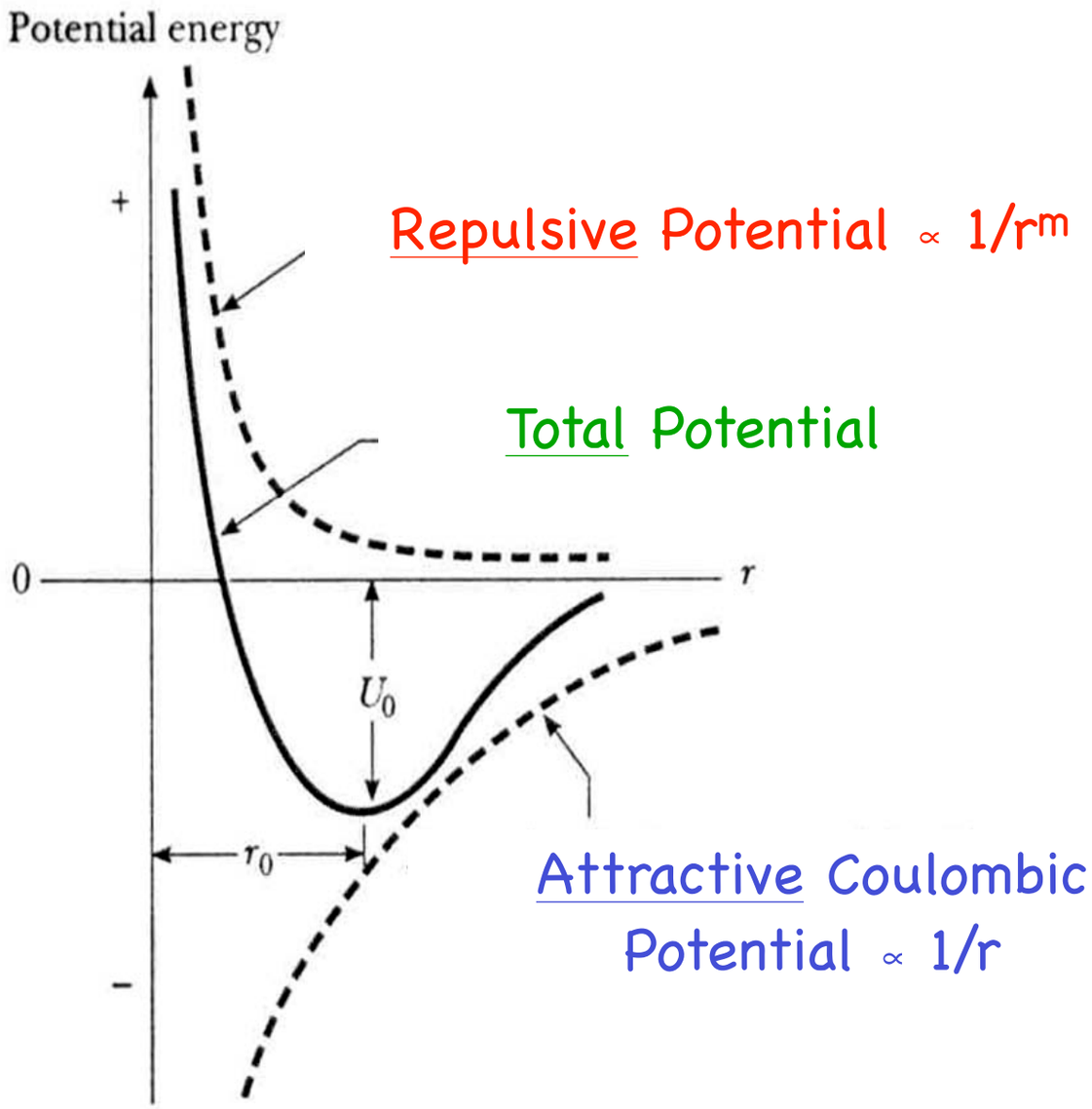
Navier-Stokes Equations



$$
\begin{cases}
\dfrac{\partial u}{\partial x} + \dfrac{\partial v}{\partial y} = 0 \\
\dfrac{\partial u}{\partial t} + u\dfrac{\partial u}{\partial x} + v\dfrac{\partial u}{\partial y} = -\dfrac{1}{\rho}\dfrac{\partial p}{\partial x} + \nu\left(\dfrac{\partial^2 u}{\partial x^2} + \dfrac{\partial^2 u}{\partial y^2}\right) \\
\dfrac{\partial v}{\partial t} + u\dfrac{\partial v}{\partial x} + v\dfrac{\partial v}{\partial y} = -\dfrac{1}{\rho}\dfrac{\partial p}{\partial y} + \nu\left(\dfrac{\partial^2 v}{\partial x^2} + \dfrac{\partial^2 v}{\partial y^2}\right)
\end{cases}
$$

What is a **wave**?

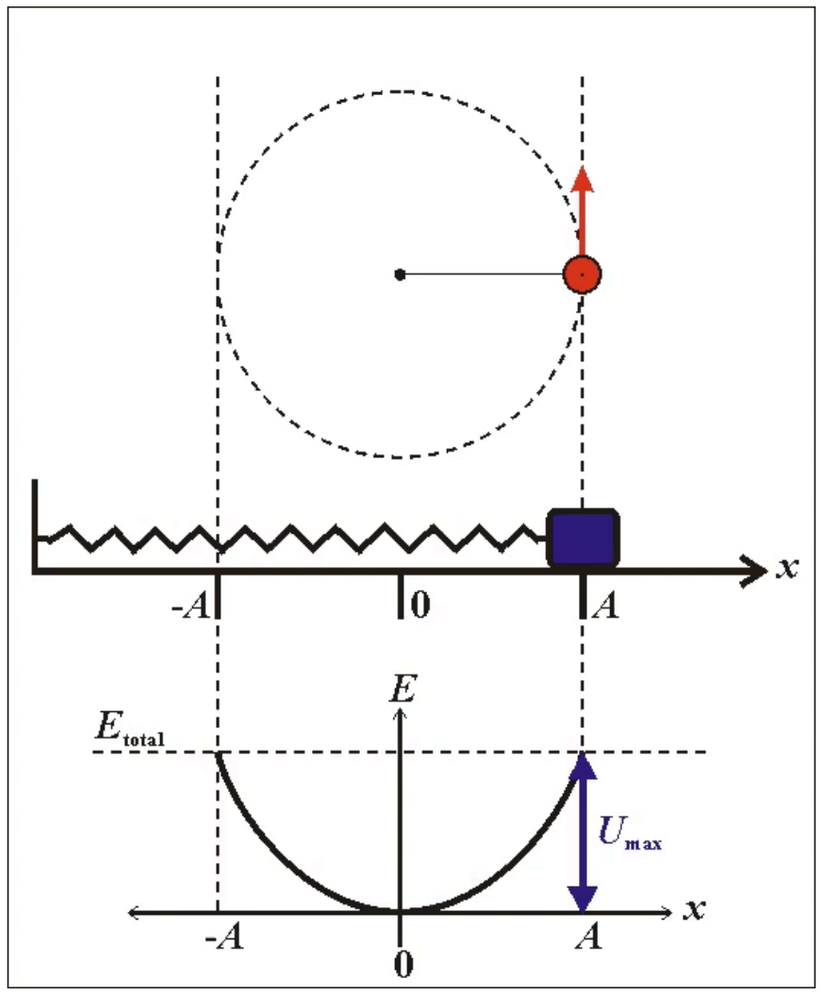
Small perturbations of a **stable** equilibrium point → **Linear restoring force** → **Harmonic Oscillation**



Repulsive Potential ∝ $1/r^m$

Total Potential

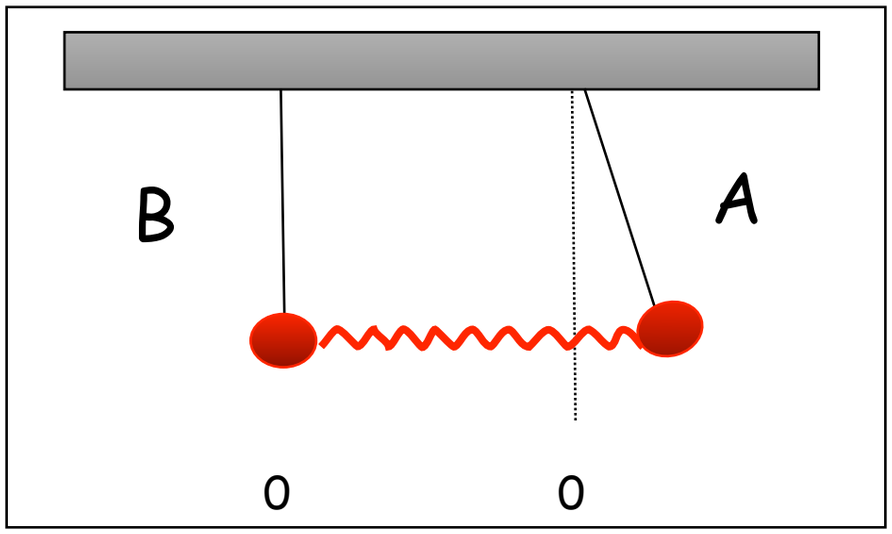
Attractive Coulombic Potential ∝ 1/r



What is a **wave**? - 2

Small perturbations of a **stable** equilibrium point → **Linear restoring force** → **Harmonic Oscillation**

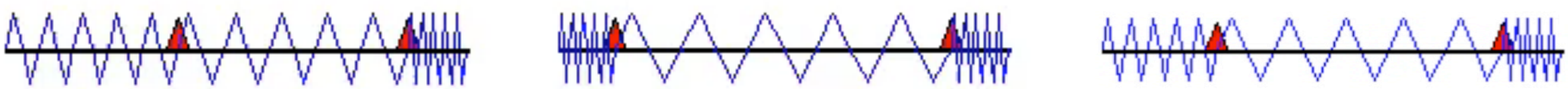
Coupling of **harmonic oscillators** → the disturbances can **propagate**



What is a wave? - 2

Small perturbations of a **stable** equilibrium point → **Linear restoring force** → **Harmonic Oscillation**

Coupling of **harmonic oscillators** → the disturbances can **propagate**, **superpose** and **stand**



Normal modes of the system

What is a **wave**? - 3

Small perturbations of a **stable** equilibrium point → **Linear restoring force** → **Harmonic Oscillation**

Coupling of **harmonic oscillators** → the disturbances can **propagate**, **superpose** and **stand**

General form of LWE

$$\frac{1}{v^2}\frac{\partial^2 \psi}{\partial t^2} = \frac{\partial^2 \psi}{\partial x^2}$$

WAVE: organized **propagating imbalance**, satisfying differential equations of motion

What is a **wave**? - 3

Small perturbations of a **stable** equilibrium point → **Linear restoring force** → **Harmonic Oscillation**

Coupling of **harmonic oscillators** → the disturbances can **propagate**, superpose, stand and be **dispersed**

WAVE: organized propagating imbalance, satisfying differential equations of motion

Organization can be destroyed, when interference is destructive

non linearity → **Turbulence**

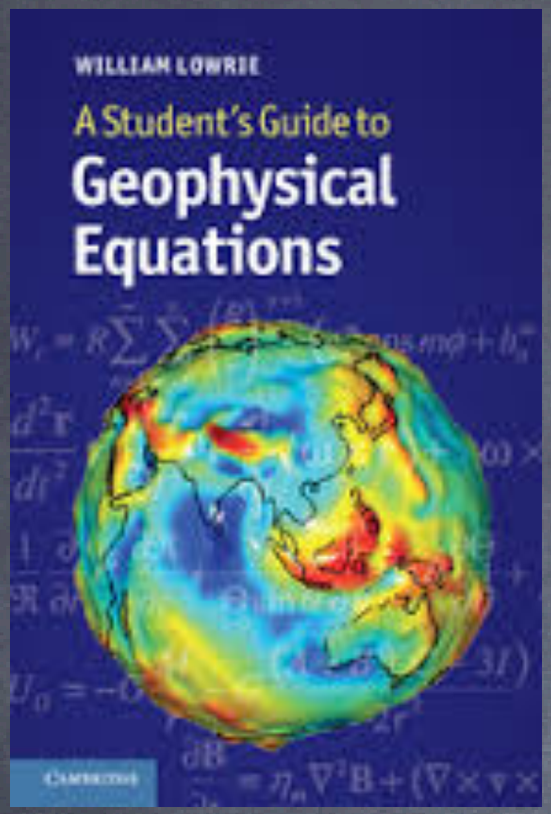
strong scattering → **Diffusion**

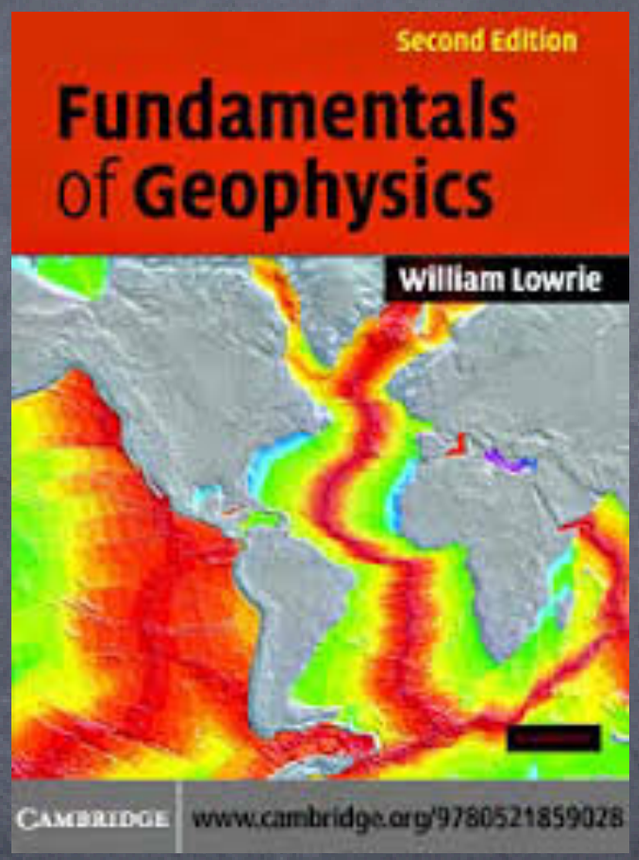
Exceptions

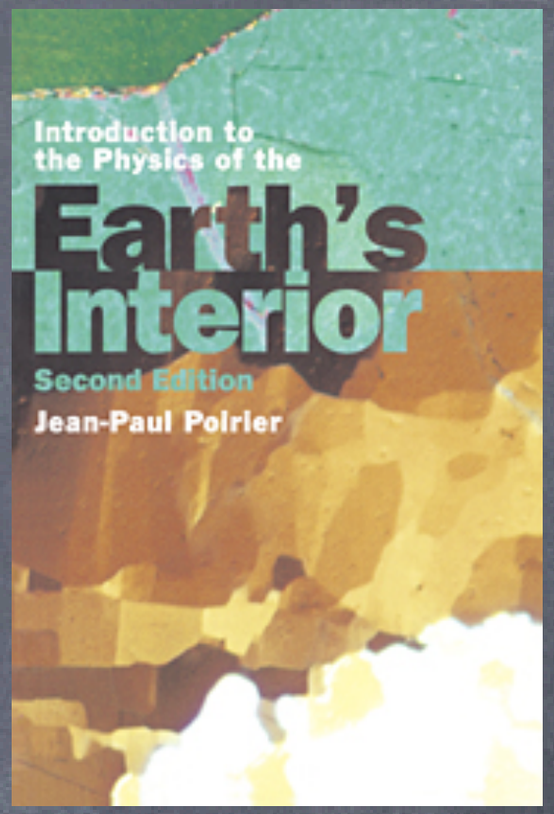
Solitons

Phonons

Alcuni Links







http://www.physicalgeography.net/fundamentals/contents.html